

Innovation For Sustainability

African and European Perspectives

Edited by Mammo Muchie and Angathevar Baskaran



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Innovation For Sustainability: African and European Perspectives

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Innovation for Sustainability: African and European Perspectives

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DEDICATION

Mikael and Adey Muchie and all the children of
Africa to stand up and innovate a strong, free,
confident, independent and proud Africa.

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Preface

The South African Research Initiative (SARChI) started the research applying the innovation systems theory approach to African problems of development and structural transformation since 2008. Throughout the last four years the SARChI chair has concentrated research on innovation to address the challenges of African development, inspired by the vision that Africa's bright future is better created by taking action rather than predicting a destination to reach at some unknown date.

The SARChI started the African Journal of Science, Technology, Innovation and Development in 2008 and have published four issues each year. It is the expectation that six issues will be published in 2013 with Taylor and Francis publishers. This has been an important outlet for emergent African researchers as nearly 70 per cent of those who publish in the journal are Africans, both in Africa and abroad. The objective is to create a publishing outlet in Africa with ISI listing. This will enable researchers to produce and publish research papers that are peer reviewed with high impact factors. The African Journal of Science, Technology, Innovation and Development are firmly on track in achieving the recognition and rating that will make it sustainable. It is one of the key milestones of the DST/NRF Research chair in innovation and development that Tshwane University was offered. The journal has a website: www.ajstid.com.

This book series is another milestone initiated by the SARChI chair. This volume has earned the distinction in 2012 of being the first to start the production of a series of books on the systematic application of the innovation system approach to the challenges and opportunities of accelerating and fully realising the making of an African national innovation system. The application of systems of innovation framing and theories to African problems of development is still new. The field has been dominated by development studies. This book series offers an alternative by proposing systems of innovation approach to generate knowledge, learning and competence-building in Africa.

However, combining innovation systems with development economics remains problematic. Finding ways to make the synthesis that generates insights, learning, theorems and workable policy directions, remains a big challenge. It is an even bigger challenge to bond in a system the interlinking of economy, space, ecology and social wellbeing. More research is needed to advance this new combination and enable renewable, alternative energy to create sustainability – socially, ecologically, economically and spatially.

This book series will spare no effort in trying to fulfil the demands of the much needed research and knowledge production.

– *Mammo Muchie and Angathavar Baskaran*

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Introduction

Mammo Muchie

We live in a world where there is a growing threat to nature that can eventually lead to a bigger threat to human well-being if there is failure to respond to all the warning signals. The innovation system theory has to deal with climate change as it generates the intellectual tools to promote development. A unified innovation system theory that integrates the eradication of threats to nature with the promotion of development is critically important to advance an original pedigree and trajectory of epistemology. Africa must learn and appreciate the costs to itself from the way Europe industrialised. It can neither follow and/or imitate the European pattern of industrialisation. It has to include in its own development agenda both meeting social needs and choosing a path of development that would not bring ecological harm in the process. The African innovation system has to evolve in a nature protecting – rather than hurting – system; in addition, social needs must be met rather than exacerbating the social inequalities path of development. Given the pressures of navigating in a globalised world economy from a weaker position in the international division of labour, this is not an easy task.

There has been an acknowledgement that the way industrialisation took off both in the earlier industrialised and newly industrialised economies, was by exploiting and injuring nature. Human induced climate change is one of the results of the specific path industrialisation has taken. Economic development has continued to this day being mainly driven as a process that is both polluting and energy intensive. The reports from the International Convention on Climate Change identify growing GDP as the main sources of carbon emission. A nature nurturing rather than hurting path of economic development has not been created yet. The dilemma is that there is a need for a shared responsibility by all, to protect nature, and a desire by each nation in the world not to be deprived from the right to grow and develop, as the major northern economies have done. The problem of winning those who wish to develop yet to share responsibility for nature, and those who have already industrialised to share responsibility for both nature protection and poverty eradication simultaneously, has been difficult to realise in practice, though it has been easier to state it in words.

About 20 per cent of the world's population live in the industrialised North and occupy about 80 per cent of the world environment and economic space. Governments have to acknowledge that their contribution to carbon

emission is not the same and that therefore the financial burden cannot be shared equally.

The ongoing economic crisis seems to create a renewed challenge to deal with both poverty and climate change as a priority. Many nations are now concerned with getting their economies on track. Naturally, economic growth and reducing emissions are two different priorities in public policy. Aid to reduce poverty will be cut as carbon emission targets too. Both are at the bottom of the political agendas, as coming out of the economic downturn comes first. For their part, developing countries prioritize growth and poverty reduction with more urgency than climate change and reducing carbon emissions. Implementing a shared and differentiated responsibility when states follow different interests will not be easy.

Shared responsibility for the planet can only mean differentiated responsibility. It is shared because all humanity is responsible to nurture and not torture nature. But the way history evolved shows uneven economic, social and political distributions and inequalities where the torture of nature and people took place. What this means is that it is fair to suggest within the shared responsibility that those who benefited but got away with contributing to climate change need to contribute more than those who did not spoil nature. There is a historical difference in the way industrialised and industrialising countries contributed to climate change. Such important differences bring differentiated responsibility to achieve shared responsibility.

One area that can be utilized to bring the divergent interests to converge is finding an agreed application of science, technology, engineering and innovation. Technological innovation and diffusion may be part of the solution. Technologies to mitigate emissions are mostly available in the industrialised countries. In the developing worlds, climate change impacts are mostly agricultural, and despite the mitigation, adaptation technologies are in high demand. The other part of the solution is a shared and comprehensive division of the costs of these technologies.

For the concept of shared responsibility to have any meaning, there must be the willingness to think beyond self-interest, to open the future to long-term perspectives – to think not only for this and tomorrow's generations – but for all generations that can beat the fear of time. The right of humans to exploit nature without restraint is wrong. The social inequalities and hierarchies among nations, states and businesses constrain the capability which needs to be forged to develop a shared responsibility in dealing with and responding to common approaches, to mitigate the problems stemming from climate change. The contributions made by different countries, private and other actors to ecological damage, is also differentiated. Recognition of these differentiated carbon emission scales and acknowledging to refrain

before all else, will provide an example to others not to repeat a high carbon emission and ecologically unfriendly route, as is mainly the case now. This pattern must be reversed and a low carbon emission route needs to be followed by all nations immediately to save the planet.

In 2005 thousands of the world's leading scientists reviewed the state of the planet and compiled a report called: 'nature on the brink'. This report contributed to re-open the debate on human stewardship of the planet. It appears that alarm bells have been sounding out across the world that climate change must be addressed. The contributions made by certain different countries, private and other actors to the crises of nature is also differentiated. The countries that contribute most to climate change are reticent to compare climate change with international security and the competitive pursuit of national economic interest. Wolfgang Sachs, in his book: 'The Greening of the North', says if the entire global population discharged as much carbon dioxide as the Germans, humanity would need five planets for nature to be able to process these emissions. A German citizen discharges less than 12 tonnes per year while a US citizen discharges 20 tonnes! Imagine how many more planets might be needed if the benchmark is calculated from the US citizen carbon dioxide budget.

If the crises of nature are to be stopped or alleviated, then major changes have to take place on how humans reconnect with nature. There is a need for a revolution in lifestyle changes, changes in human reproductive behaviour, and restraint in the unbridled promotion of commoditisation by shrinking the global commons. The rejection of totalitarian futures has been replaced by the prospect of launching a fully commoditised world. Commoditisation privileges private vision over public vision. Private vision of the future tends to polarise rather than engender the ability and imagination to create shared responsibility to protect and nurture nature, and cope and mitigate human activities that contribute to climate change.

Shared responsibility is desirable but difficult to implement. The multitude of conflicting human populations grouped into classes, nations, states, religions, races, genders, ethnicities: their equally conflicting ideas of an end-goal to strive for, their often non-inclusive and non-accommodative institutional devices, and the technological abundance that is not matched with an abundance of the human spirit and generosity to solve problems of injustice and climate change – all these impose constraints in bringing out the real issues.

Shared responsibility encounters these differing entities and agents living in constant tension. It is hard to see how they can balance and reconcile their divergent values, norms, beliefs, interests and prejudices in order to act on climate change as a shared responsibility. The conflicting private vision is blind to everything but the pursuit of self-interest. The

push to make private sphere dominate the public realm and the various commons would not encourage vision to predict a sustainable and non-problematic future.

For the concept of shared responsibility to be meaningful, there must be the willingness to think beyond self-interest, to open the future to long-term perspectives – to think not only for this and tomorrows generations but for all generations that can beat the fear of time. There is thus a need to think not for a century but a millennium – and even millennia – to open a bright future for nature, people, and to open the future to accurate modelling and foresight.

If the shared and differentiated responsibilities are observed and the differentiated capabilities are employed, nature will be factored in the making of innovation systems. A particular way of translating differentiated responsibility into shared responsibility was supposed to be supported internationally, including financial and technology transfer. Industrialised countries have developed with a kind of economic development logic that nature is an infinite sink. If they want developing countries not to develop using the same logic, they have to step in and assist these developing countries in the interest of protecting nature. In addition they already have the knowledge and technological capability to address climate change, if they so wish. They must take leadership to tackle climate change. However, developing countries must also participate and do their share. Assistance from the developed world supplements and enhances addressing environmental issues as they undertake development concerns.

What is needed to be done is clear. What is not clear is the actual translation of the inclusion of nature with the same role in the national system of innovation as economic and industrial development. The industrialised countries balk when it comes to the provision of financial assistance. At the Rio conference an estimated US\$600 billion was said to be needed to implement various environmental programmes in the developing world, however, only 25 per cent of this US\$125 billion was pledged. It is true that this amount was not disbursed in the envisaged time frame. The pledge to meet the promised target of 0.7 per cent of GDP from rich economies as overseas development assistance (ODAs), did not materialise either. To date no more than five countries have reached this goal, and the promised US\$125 billion has not materialised. Instead the rich nations have proposed nature protection must also enter into the market and to the economy to solve the problems of environment and development.¹

The main challenge is to integrate nature protection into the making of systems of innovation. The system of innovation should be developed as a sustainable and ecologically underpinned system of innovation. The challenge is how to create a unified system of innovation theory.

Originally the system of innovation developed mainly to explain how the interactions of actors, activities and policies stimulate different rates of economic growth. This may be necessary and may not even be sufficient to address the dilemmas and challenges of where development will ultimately take the world. It is now fully acknowledged that development has taken place at the expense of both nature and social and spatial inequalities that have not addressed the needs and well-being of those who lose in the process. Systems of innovation theory that cannot ignore the social and environmental consequences need to be developed. A unified system of innovation needs to factor explicitly in both nature and alleviating social and spatial inequalities.

A unified system of innovation that combines science, technology, engineering, innovation, and development that explicitly factors the social economic objectives with environmental and social and geographical disparity alleviation objectives, is much needed and waiting to be written.

In Africa this unified system of innovation theory still remains to be theorised. The nation, the system and innovation need to be contextualised. The fact that the system of innovation is on the agenda is positive. However, much research is still needed on the case of Africa's economic development challenges to explore how science, technology, engineering and innovation (STEI) can be integrated in designing an African development agenda that simultaneously integrates the economic, ecological, social and spatial variables simultaneously. How far have the processes of constructing the African development agenda taken these four variables – Economic, Ecological, Social and Spatial (EESS) – and has both explicitly sought and embedded science, technology, engineering and innovation (STEI) in their evolutionary dynamics? How STEI has driven African development by becoming the primary vehicle to create the transformation of the currently largely African agricultural and primary resource-based economy to an innovation anchored knowledge-based economy? As the national system of innovation concept has been appropriate to select science, technology and innovation for economic development, there should be a demand to introduce nature explicitly as part and parcel of the science, technology, engineering, knowledge, learning, and innovation within a spatial context as a relevant and important ingredient to bring protection of nature and transform economic development into socially and ecologically sustainable structural change. It means the system of innovation has to be reconceptualised and re-framed with the inclusion of nature as central and not as an added-on variable to the very process of economic development. It means a system of innovation as a conceptual lens has to re-define what productivity, growth and economic development mean. It is not just the growth of GDP that matters, it should also feature in ecological well-being and should add gross ecological

product (GEP) that may slow GDP, but with the gain of the growth of GEP. This means that the dynamics of the economic growth process is measured by the validation of not having ecological transgression and violation. Thus the economic growth calculation also changes by re-framing and redefining knowledge creators, product and process producers and users and policy makers to interact and learn by taking directions that enhance productivity synthesis of ecology with economy. It also influences the methodology for collecting and examining data to select which problems and directions are helpful to take and which are not. The inclusion of the ecological variable modifies also the various elements the concept of system of innovation identifies, making the constituting components of the whole system to interact with a new logic. Which are the most or the less significant interactions in relation to actors, activities, institutions in the process of knowledge creation; diffusion and exchange now are done with the inclusion and not exclusion of ecological variables. It becomes critically important that failure to include environmental factors in the beginning of the economic process and spectrum is rejected. Inclusion of ecological variables after the playing out of the economic growth and productivity – no matter how it is done – will not be credible. System of innovation as a heuristic concept has been developed to focus on knowledge creating activities among various actors and institutions that provide competitive advantage in the long-term. But the inclusion of ecological variable alters this heuristic choice. It is not merely economic competitive advantage, but also ecological competitive advantage that guides the long-term sustainability of the economic growth trajectory and evolution. There is a need to make a system of innovation flexible and inclusive. The main characteristic of the system of innovation has to redefine and include ecology to various geographic regions as well as various organisations. For example, the type of activity could change from (simple to complex or from small to big). The spatial unit and boundary can shift or vary from local to national, regional or global. The actors or stakeholders could change from small to large private firms, private–public firms or big corporations. Institutions could vary from local to national, regional or global. The sectors or industries could vary. The concept of innovation system relates knowledge creation, diffusion and exchange to the actors, activities, institutions, spaces and their interactions. The interactions in the process of acquisition, diffusion and transfer of knowledge can form systemic properties and functions around the innovation system as the core stimulator of the ecologically underpinned economic development process. The concept of an innovation system captures the specific interaction of science, technology, engineering, knowledge and innovation as the driving variables of the spatial, sectoral and institutional arrangements in the context of the activities and actions, to bring about an ecologically knowledge

anchored national economy of production that combines economic growth in GDP with ecological growth in GEP. The main problem to address is how an innovation system can be re-worked and adapted by the inclusion of the ecological variable to implement a strategy where producers and users interact with enhanced learning, economic and innovative performance. The added values from applying the ecologically sensitive system of innovation include the following: The creation of the national system of production and consumption that is ecologically inclusive with learning, innovation and competence building skills that can network ideas, economies, actors and institutions. There is a need to bring about resource circulation to prevent lopsided and uneven development between urban and rural areas, formal and informal activities in various African economies. Learning interactions emerging from the process of applying science, technology, engineering and innovation into production. The influence of the social, cultural and institutional particularities in making science, technology, engineering and innovation in changing, creating, mobilising and distributing resources. The system of innovation acknowledges the significance and relevance of the African varied spatial context for economic change despite globalisation.

There have been different approaches within the innovation system. They have not all included the ecological variable. Some approaches stress more on the problem of development and economic competitiveness of developing countries through the application of science, technology, engineering and innovation without entirely excluding others. Other approaches concentrate more on industrialised economies' institutions and policies to absorb, modify and diffuse new technologies without excluding others. Others propose a global reach where independence is the understanding of the process of innovation, learning and competence building for economic growth, development, competitiveness, efficiency and productivity. They all need to include ecology, and re-design the economic growth and development logic entirely.

Another critical change that developing economies in general and African economies in particular confront, taken separately or together, is also creating, managing and sustaining developmental connection amongst agriculture, manufacturing and services within each state or across Africa as a whole on the basis of environmentally friendly trajectory. The failure to date to structurally transform agriculture and build a manufacturing African economy, may open the opportunity to re-think how an African green revolution can be combined with Africa's industrial revolution. Rather than seeing what was not accomplished, it may be prudent to focus on what can be achieved. The best way of predicting a future is said to be by creating it. Daring to create the African future requires that the leadership and the people are receptive to recognize, value, understand and

appreciate that it may be easier to plan the structural transformation of Africa's green agricultural revolution in tandem with building an ecologically friendly industrial Africa, rather with collaborative dynamics than going it alone – one by one – fragmented by each state. This integration vision must prevail if indeed Africa's structural transformation that brings about a co-evolution of transformation of green agriculture and minerals, with a carbon-emission free manufacture, is going to be realized without further waste of time. There is a real need to appreciate a new epistemological approach to the way economic development is to be understood, used and applied in Africa.

There is also a need to create a new epistemology of hope by employing emancipatory, unifying, meta-epistemic conceptual framing to anchor on an, original, high quality and grounded perspective of the African development agenda for inclusive, just, sustainable Pan-African integrated economic system based on knowledge exchange, the exploration of indigenous community based knowledge and the use and application of science, technology, engineering and innovation for a Such reorientation in anchoring the African development agenda with ecological underpinning would require the following to be explored as new conceptual lenses for examining the African development dynamics:

There is a need to undertake a research re-orientation. Theories of economic development that dominated policy thinking in Africa need to be critiqued systematically.

There is a need to open the door for theories that are contextualised in the African setting and that can serve also as lenses to illuminate the empirical reality and specificity of the African situation.

The chapters in this volume attempt to include the environmental discussion to the development process both in Africa and Europe. The chapter by Mammo Muchie discusses the uptake of environmentally sensitive innovation to transform production systems in sub-Saharan Africa. The objective is to identify empirically the degree to which firms in sub-Saharan African countries have experience with environmentally sensitive technology uptake. Examples are sought from reports of cleaner production activities from Tanzania and Zimbabwe. Invariably cleaner production is externally induced. It is not created internally as part of a firm's evolutionary dynamics, selection, common sense, routine or set of activities. From the technology to the consultants, they appear to have originated from outside. The barriers to the uptake of ESTs into African firms will be identified and the wider context and ideas for their internalisation to enhance firm capability of environmentally anchored production requires the synchronised deployment of national policy framework, industrial policy, technology selection and production, that is creating a robust national system of innovation for the economy.

The chapter by Patrick Bond on climate debt owed by industries and over-consumers of the Global North to Africans and other victims of climate change, not responsible for causing the problem, has accrued by virtue of the North's excessive dumping of greenhouse gas emissions into the collective environmental space. Damage is being accounted for, including the more constrained space the South has for emissions. This historical injustice – and 'debt' – is now practically universally acknowledged, and reparations plus adaptation finance are being widely demanded. In Copenhagen, the 2009 United Nations summit on climate change witnessed a great deal of theatre over conceptual problems, including who should make emissions cuts and to what degree; should markets be the main mechanism; who owes a climate debt; how much is owed; and how the debt should be collected. The willingness of African heads of state to raise the matter publicly beginning in mid-2009 was notable, but their inability to ensure political solidarity led to the imposition of the Copenhagen Accord on 18 December, in a manner that sets back the cause. Civil society needs to continue working with Latin American governments, especially Bolivia's, to advance this struggle in coming months and years – even though it is in the self-interest of African rulers to join the campaign more forcefully and durably than they did in 2009. Without African government support for the concept, systems of climate debt payment won by civil society designed to bypass the African national state (such as Basic Income Programs) will be ever more attractive.

Kinda Somlanare Romuald examines the existence of convergence and the importance of education on carbon dioxide growth per capita, over the period 1970-2004 for 85 countries. He uses panel data and applies GMM-System estimation. This rigorous approach takes into account the observed and unobserved heterogeneity of countries, and solves the endogeneity problems associated with some variables. The results suggest a divergence in per capita carbon dioxide emissions around the world, and that education is not a factor in carbon dioxide emissions growth. Contrary to commonly held beliefs based on intuition, we provide evidence that, in developing countries, there is no convergence, and that education is not a factor in carbon dioxide growth. In developed countries, we find a convergence for per capita carbon dioxide emissions. Education was found to be a factor in pollution growth, although its effect is mitigated by the presence of political institutions.

Rainer Walz discusses the green markets of the future. He argues that competences for green technologies in Newly Industrializing Countries (NICs) are becoming increasingly urgent from a global perspective. These technologies open up the opportunity for reducing emissions and modernizing the infrastructure, and the prospect of exporting them can add an incentive for NICs to push in that direction. The chapter analyses whether or not

NICs have already obtained some of the competences necessary to exploit these opportunities. It uses innovation indicators for publications, patents, and trade. The results indicate that some of the NICs, among them South Africa, have already started to develop the necessary build up of competences, but others are unlikely to benefit from the economic opportunities. The wide range of results for different green technologies within South Africa underlines the need to perform such analysis on a disaggregated level. Furthermore, the green technology development is embedded in the overall performance of the South African innovation system, and depends on its improvements. A widening of the policy focus from a narrow definition of R&D institutions towards both the demand side and environmental regulation is necessary. Strengthening environmental regulations in South Africa must not be seen as a trade-off between environmental protection and economic development, but as an instrument of demand-side driven innovation policy in one of the fastest growing technology sectors.

Martina Schäfer, Dörte Ohlhorst, Susanne Schön and Sylvia Kruse argue that sustainability research is aimed at meeting the challenge of dealing with important societal problems related to the 'metabolic' processes between society and nature in a global context. Besides generating knowledge about the characteristics and dynamics of the complex processes involved (e.g. climate change, loss of biodiversity, increasing poverty and hunger), it should also contribute to normative knowledge about how to evaluate these processes and develop strategies for social change towards sustainability. An interdisciplinary composition of research teams is necessary to deal with the complexity of sustainability problems. The normative questions and the need for decisions to be made in situations of uncertainty, additionally call for a transdisciplinary research design, involving actors from the life-world as equal partners. The process of integrating knowledge from different disciplines as well as from the life-world is a great challenge which needs to be met through methodological innovation. This article introduces constellation analysis as a methodological approach for bridging different knowledge claims, drawing on two case studies to demonstrate its application.

Britta Rennkamp discusses technological innovation and strategic knowledge as crucial to global problem solving. However in the current global governance architecture 'knowledge' is a marginal issue. Classical economic theories do not take into consideration that knowledge is not a public good, free from rival consumption and exclusion. Britta outlines the main problems with these approaches and makes an argument for the strategic knowledge that is required for global problem solution. She discusses how states can cooperate linking scientific-technological and development cooperation to achieve more sustainable development paths. Evidence

derives from bi-and multilateral cooperation experiences from Germany and South Africa.

Klaus Rennings, Peter Markewitz and Stefan Vögele discuss that radical innovations are frequently called for in order that the transformation of society to a system perceived as sustainable can succeed. The reason given for this is the greater environmental efficiency of these innovations. They review the hypothesis that radical innovations are superior to incremental innovations by reviewing the case of fossil fuel power plants in Germany. An ex-post analysis of the German R&D portfolio in the past three decades in the field of power plants environmentally shows that technologies which were radical innovations, had great difficulties in being accepted by possible investors. The future potential of radical innovations in the field of power plant technology is to be regarded as relatively low, especially due to comparatively high cost-pressure, the reluctance of utilities to take risks and the temporal dynamics of technological progress facilitating incremental innovations on the basis of conventional reference technology.

Andrew Jamison in his 'In Search of Green Knowledge' takes a cognitive approach to sustainable development. Andrew Jamison discusses how his own research path was influenced by his activism in both the anti-war and environmental movements of the 1960s. He combines activism with scholarship and discusses how knowledge production has changed in the last forty years. He depicts vividly his own story of how he moved from USA to Scandinavia at a time in the 1960s when a much broader transformation of knowledge making was taking place. This was a time when so many of the assumptions that had traditionally governed scientific research were fundamentally questioned and began to be overhauled. He argues that the boundaries that, for some three hundred years, had separated science and technology, and knowledge making in general, from the surrounding society have largely been broken down. The relative autonomy of academic institutions and the 'academic freedom' that were once considered essential for the health and vitality of scientific research, have been almost entirely eliminated, and even though many of those who work at universities continue to bemoan their passing, there seems to be little value in wishing that they could suddenly be brought back to life.

The integration of science and technology into society was already well underway in many branches of industry, and, of course, in the military before the 1960s, but it was accentuated enormously by the technological innovations that emerged in the 1970s: in particular, personal computers and genetic engineering. What have come to be called information technologies and biotechnologies essentially mix what had long been characterised as the separate spheres of science and engineering, and their ensuing development and societal significance have largely been based on an ever closer

collaboration between academics working in universities and people working in commercial business enterprises. Indeed, in many cases, due to the various attractions and not least the wealth that can be accumulated in the commercial marketplace, many academics have largely become 'entrepreneurs' in their attitudes, behavior, and way of life – and many universities have come to resemble business firms in their underlying modes of operation, as well as in the values and norms by which they are administered and organised. He advocates strongly how the making of green knowledge is critical to create an environmentally friendly world.

Lothar Mennicken, Wolf Junker, Imraan Patel and Oksana Buranbaeva discuss the South African-German Dialogue on Science for Sustainability (D4S) between the South African Department of Science and Technology (DST) and the German Federal Ministry of Education and Research (BMBF) was initiated in December 2007 in Pretoria, South Africa. A hundred South African and German scientists, policy makers and representatives of industries and non-governmental organisations participated in the course of the dialogue. The initiative intends to define common areas between South Africa and Germany in the field of research and development for sustainability, build future networks between the scientists and industries in both countries, initiate new research and development co-operations and contribute to the dissemination of scientific and technological knowledge. Importantly, the dialogue aims to provide a forum for the two parties to share knowledge and have focused discussions on a range of mutual policy and strategy challenges.

CONCLUDING REMARK

The chapters in this volume address both in Africa and Europe how the combination of environmental concerns with economics is handled by specific topics selected by the authors to address and explore. The introduction of green market can potentially cause the environment to be driven by economic calculation rather than drive the economy with sustainability. This tension remains because the different actors that join the environmental cause bring their own main functions to prevail by adding the environmental issue as part and parcel of their own calculative matrix. The main goal of business remains to continue to make business. This can naturally bring challenges on how to maintain the balance between realising the ecological imperative with the economic calculative logic.

A radically new approach is needed to create a new paradigm where the very calculation of economic growth is measured by how much ecological health is realised fully. This naturally means that ecology must not

be subjected to economic calculation; on the contrary, the economy must fall under ecological imperative and any economic growth that violates the ecological constraint must be questioned.

This broader objective of re-adjustment between ecology and economy requires a paradigm shift which is not clear yet it is recognised by all the actors from the North and the South. Failure to implement the differentiated and shared responsibility is a problem; a more substantive concern is how to combine economic calculation without ignoring but by explicitly including the ecology.

As Europe and Africa have geographical proximity, it is important they find a way to share the costs and benefits of harvesting solar energy. The African solar energy network (www.Ansole.org), is an excellent initiative that can serve as a useful way to bring resources from all sides to make Africa and Europe become allies for creating renewable energy for sustainable development.

A critical way to advance is to create systems of innovation that incorporate sustainability. More systematic research in this field is much needed; the papers in this volume have highlighted some of the critical issues that need to be addressed with urgency. More research in this field is still waiting to be done.

NOTE

- 1 Press Release Rio Plus 5, 1997, New York, USA.

The Uptake of Environmentally Sensitive Innovation to Transform Production Systems in Sub-Saharan Africa

Mammo Muchie

SUMMARY

The objective is to identify empirically the degree to which firms in Sub-Saharan African countries have experience with environmentally sensitive technology uptake. Examples are sought from reports of cleaner production activities from Tanzania and Zimbabwe. Invariably cleaner production is externally induced. It is not created internally as part of a firm's evolutionary dynamics, selection, common sense, routine or set of activities. From the technology to the consultants, they seem to have originated from outside. The barriers to the uptake of ESTs into African firms will be identified and the wider context and ideas for their internalisation to enhance firm capability of environmentally anchored production requires the synchronised deployment of national policy framework, industrial policy, technology selection and production, that is making a robust national system of innovation for the economy.

INTRODUCTION

One factor for focusing on cleaner production practices in Africa is the possibility of building in environmental concerns in Africa's quest to industrialise. In comparison to the industrialised countries, the industrialising countries of Africa can be seen as 'a green field economic space'. The condition for setting up cleaner production centres to help design and plan both environmentally and economically sound industrial systems is open in Africa. The fact that Africa has no locked up industrial system is a plus in the sense that it does not have to pay the huge costs to readjust and retool massive industrial structures built over many years. It is possible that national environmental laws could enforce the

requisite regulatory regime to combine environmental planning with a wealth-creation planning in Africa's relatively more agrarian setting than in industrialised countries.

Planning international technology transfer in the form of environmentally sound technologies (ESTs) uptake into African firms is therefore an important strategy to combine development with poverty eradication and environmental security. African development should and can proceed by internalising environmental constraints. There is no alternative to imagine and design strategies to bring about development with environmental health and conservation. A new model of ecologically underpinned industrial evolution can be tried in Africa. An important factor to the input of African industrialisation is relentless thought, consideration and incorporation of environmental constraints. An important output is measurable gains in environmental conservation. Thus theories, concepts and production activities for facilitating Africa's industrialisation have to be more exploratory and imaginative.

The attempt to introduce ESTs into African firms can be seen as a break-away with known patterns of industrialisation. The cases will be examined as part of the search to reveal any light on the alternative road of ecological industrialisation. We shall examine the conception and practice of ESTs' uptake in Tanzania and Zimbabwe from reports and conversations the writer had with various consultants, especially from UNEP/UNIDO involved in cleaner production assessments, mostly as part of the set up of National Cleaner Production Centres (NCPCs). While interpretation and analysis is from this author, the information is taken from reports and notes from interviews and conversations of international UN consultants. Both Zimbabwe and Tanzania have benefited from the setup of the UNIDO/UNEP assisted National Cleaner Production Centres. The latter have tried to spearhead cleaner production assessments in specific industries by promoting cleaner production practices via dissemination, workshops, training and courses. The Zimbabwean cleaner production centre has been host to the second meeting of the NCPC group of countries. Cleaner production training at the shopfloor for workers has been explored in Zimbabwe. Training programmes for future consultants in CP has been developed. Though CPC-Z has provided training, it does not certify the training and is seeking assistance from a Norwegian DNV to certify trainees both in companies and as consultants. Companies in Zimbabwe try twinning with foreign companies to create technology partnerships. CPC-Z is not inserted in any identifiable pattern in Zimbabwe's superstructure for research and development or production. Its current status remains unclear.

CASE STUDY OF CLEANER PRODUCTION EXAMPLES FROM TANZANIA

Consultants claim in their reports that in Tanzania many industries are uninformed about cleaner production concepts. There are, however, a number of organisations involved in searching for ESTs. Some of these are: the Tanzanian Industrial Research and Development Organisation (TIRDO), the Commission on Science and Technology (Costech, the Institute for Production Innovation (IPI) and the Institute for Resource Assessment (IRA).

The introduction of cleaner technologies in Tanzania was carried out through a project based on the collaboration of an international donor DANIDA, Government's ministry of Tourism, Natural Resources and Environment, industry, academia and R&D institutions. The project was called Cleaner Environmental Production in Industry in Tanzania (CEPITA), and it was set up with the mandate to:

- generate a systematic framework for introduction of cleaner production technologies with the aim of waste prevention at source, minimisation of water, chemical and energy consumption within selected industries,
- demonstrate that economic benefits can go hand in hand with environmental benefits,
- formulate an effective pollution prevention policy and strategy,
- train industrial personnel in cleaner production and
- create cleaner production within government, industry, academia and civil society institutions (Migiro, 1996).

Various reports indicate that Tanzania has experience of cleaner production assessments at a firm level. Twelve companies have been reported selected for cleaner production assessments at the pilot phase. The sub-sectors from which the companies came were: three in metal and electroplating, one in glass, one in cement, two in food and beverage processing, two in soap, two in textile and one in fibre processing. The companies were Galco, Kioo Ltd., Medicare, Tanga Cement Company, Bonite bottles, Sunflag, Arusha Galvanising Company, Mwanza Voil, lake Soap, Zana Za Kilimo, Mbeya Textile Mill and Kimamba Fibre Estate (UNEP, 1996). Cleaner production options were considered, a total of 169 options were reported. Of these 105 were found feasible by the industries and are expected to be implemented. Further feasibility studies have been planned on more industries (UNEP, 1996).

The Cleaner Production Centre of Tanzania has taken over the work of CEPITA. It has been reported to organise demonstration projects on

six industries on mainland Tanzania and ten industries on the island of Zanzibar (UNEP, 1996). The sub-sectors in Dar es Salaam include cement, electroplating, beverages, iron and steel, and soap/detergents. In Zanzibar, they include food and beverages, essential oils, tobacco, soap, motor repair workshop, fuel transportation/marketing, and motor trading. The companies in Dar es Salaam are: Tanzania Portland Cement Co. Ltd., Tanzania Breweries Ltd., Colgate-Palmolive Ltd., National Bicycles Co., Shivji & Sons Ltd. and Motisun Holdings Ltd. Those in Zanzibar are: edible Oils, Clove Stem Oil Distillery Plant, Zanzibar Bottles (Coca-Cola Company), Bakhresa Flour Milling Company, Bakhresa Soap Ltd., Motor Trade Corporation and Tractor Repair Workshop (UNEP, 1996).

The demonstration projects provide an enabling environment to identify cleaner production options barriers to implementation, technical feasibility studies and investment costs. The result from the demonstration is disseminated to other companies. In this way best practice is thought to be diffused to more and more firms. The Cleaner Production Centre of Tanzania is supposed to act as a sort of information clearing or resource centre on cleaner production. To date, there is no information on whether CPCT is undertaking technical evaluation to identify and select viable cost effective alternative indigenous technologies to disseminate to firms.

There is very little technology research in Tanzania and almost all technology has to be imported from abroad (Ruijters, 1996). Most of the ESTs appear as incremental innovations mainly in the form of end-of pipe treatment, good housekeeping, use of waste as a by-product, techniques for eliminating hazardous chemicals and a few production-integrated technologies.

In Tanzania, a number of organisations claim capacities to undertake technology needs assessment and selection. The Clean Production Centre has the explicit purpose to build capacity for identification, demonstration and promotion of knowledge on waste minimisation and cleaner production. The Centre for Energy, Environment, Science and Technology, TIRDO and Costech claim to make technology assessments. While these institutions say they can assess technology options, industry has to seek out for their help. There is no such voluntary seeking out by industry for information on ESTs (Ruijters, 1996). Some institutional elements, which can serve as a national system of innovation, exist and they need to be strengthened.

If much of the technology is imported externally, pressure for ESTs uptake has to come from the same external sources from which the technology is bought or taken. Those who provide loans to Tanzanian industry are also likely to attach specific environmental requirements as 'condition' to their loans. Other routes of ESTs uptake relate to:

- possible benefits accruing to local firms from a parent company or partner which has incorporated ESTs in its production system;
- if legislation on health and safety grounds prevent companies from polluting local areas;
- if cleaner production is found more economical than the dirty production it replaces; and
- if investment costs for introducing cleaner technology will be compensated by higher gains as a result of the uptake of ESTs by firms (Muchie, 2000).

Disincentives for EST uptake can be triggered by regulations, consumer and advocacy pressure, legal threats and product boycott. Other measures that can act as incentives include clear and measurable gain from the introduction of ESTs into firms. When there is value-added gain of efficient production and economic advantage as well as environmental gain, ESTs can compete for uptake (Muchie, 2000).

EXAMPLE OF CLEANER PRODUCTION ASSESSMENTS IN ZIMBABWE¹

In Zimbabwe a cleaner production assessment has been undertaken on Zimbabwe sugar refineries (Harare and Bulawayo), and Cairns Foods Ltd. (Harare). The two sugar factories operating under Zimbabwe Sugar Refining Corporation, process 11 000 and 10 000 tonnes of cane per day. They produce raw sugar, white refined sugar and brown sugar. The two sugar factories also operate ethanol plants using final molasses. The problem with the sugar factories is insufficient rainfall. The Harare plant was established in 1953. The main equipment dates back to 1935 and new parts have been added since then. The two factories run seven days a week, twenty-four hours a day and annual throughput is 140 000 and 80 000 tonnes refined sugar for Harare and Bulawayo. The refined sugar is mainly produced for the local market while small quantities are exported to Botswana. The two factories employ just over 300 people, with the main labour force consisting of unskilled labour, technicians comprising one sugar technologist for each company, laboratory technicians, and production maintenance supervisors supporting divisional managers. The Harare factory had a production and general manager trained in sugar technology.

At the time of the assessment there was water shortage due to the drought, which hit Zimbabwe (1992–1995). The companies were faced with water rationing. If they exceeded the limits they would be charged higher surcharges. There was thus a need to conserve water. A raw material input of 480 tons per day, 225 kg lime per day and 173 kg of phosphoric acid

per day and flocculent depending on the pH of the syrup feed of the sugar refining process in the factories. Water and energy are the other inputs. The process progresses from the stage of raw material reception, weighing and storage, to batch weighing and conveyance, mingling, affixation, centrifugation, melting, screening, clarification, absorption, evaporation, further centrifugation, drying, storage, packaging and finally into packed sugar.

The areas selected for the audit focus were the following: syrup clarification (de-sweetening clarifiers), colour adsorption (bonechar cisterns), and vacuum evaporation condensate (pans and cooling towers). The reasons for the selection of the problem area are related to the degree of water wastage in the sugar manufacturing processes in the factories. At syrup clarification a lot of fresh water (42 m³/day) was being wasted to wash scum (335 kg/day) into the sewer system. Wastewater is also generated during the rinsing of cistern for 12 hours estimated at 1512 m³ per week. Condensate from the evaporation pans is generated at the rate of 28 tonnes per day. Of these 11 tonnes are lost to drain.

Cleaner production assessments have focused largely upon the technical options, feasibility and financial assessment. For example, technical recommendations to reduce water wastage included:

- i. installation of water meters to clarifiers;
- ii. diversion of char cistern water as stop gap measures to wash scum;
- iii. recommission of the press filter and reuse of water in the processes;
- iv. at the bonechar cistern recommissions the water softener and re-use water;
- v. divert excess condensation from evapo-pans for use in processes.

The cleaner production auditors found all these options highly feasible. The cost was estimated at Z\$300 000 at 14 months for the filter press and water softener.

Another company in Zimbabwe where clean production audit was undertaken was Cairns Foods Ltd. It started as a motor business in 1929 and has diversified into food and beverages in the 70s and 80s. The company employs 1 200 people and boasts of an annual turnover of Z\$162 million and Z\$228 million in 1994 and 1995 respectively.²

The manufacturing process of coffee involves roasting, grinding, weighing, blending, extraction and packaging producing two forms of coffee: ground and instant. With additives these forms can be pure or blended coffee. The inputs are fuel, water, cooking oil, coffee beans and chicory. The process involves roasting, screening and cooling. For ground coffee the process proceeds with weighing, milling, blending and packaging. For instant coffee the extraction proceeds along the line of weighing, meshing,

blending, extraction, mixing, filtration, pumping, spray drying, collection and packaging. In the process product loss occurs. Coffee and chicory are roasted and the manner of the roasting normally determines the flavour and blends. Parameters such as temperature, fluids and even the period of roasting are important to control.

The best extraction takes place when temperature, water flow, coffee and chicory mesh is constant. Holding these parameters constant yields higher efficiency, i.e. maximum extraction in a short time, using less energy and waters (yields 60–70% solid recovery). The extraction yields are minimal in the pure blends (35% average) in comparison to coffee and chicory since recoveries for chicory are very high i.e. up to 90 per cent.

The selected audit focus was extraction units and spray-drying tower. Both were selected because of the poor extraction rates and high waste problems, and high economic losses for the plant. Waste and emissions were in the form of coffee husks sludge and fumes from coffee bean roasting. The plant experiences high economic loss due to low levels of coffee extraction from coffee beans (40–60%) and the generation of large quantities of coffee lumps from the spray-drying tower contributing as much as 58 per cent. The cost of such lumps was valued at Z\$3million in the plant and warehouse when the clean production assessment began.

For the coffee plant after clean production assessment the following targets were set to:

- Increase extraction rate from the 40–50 per cent to 60 per cent realising an improvement rate between 10–20 per cent
- Reduce lumps by 40 per cent
- Reduce water consumption by 10 per cent
- Reduce energy use by 20 per cent

The cleaner production technique options suggested were for the extraction units to: (a) add a decanter vacuum filter to press liquor from the coffee waste. This was expected to improve recovery rates without affecting quality at an estimated investment cost of Z\$1 million; and (b) fit the flow meter to regulate water intake by extraction units to improve yield concentrations and improve quality at very low cost.

For high-pressure pump units it was proposed to install new pistons to improve pumping pressure of the extract through nozzles for proper atomisation and productivity. Benefits were expected to outweigh costs by 60 per cent due to the reduction of lumps, which will in turn improve plant profits by 40 per cent.

For the spray-drying tower, the cleaner production options are fourfold: (a) undo all the welded dampers on air ducts into and out of the spray

drying column, improving intake and outflow of hot air in the column at very low cost option carried out during maintenance period; (b) restore all manometers to improve pressure monitoring in the column with a low cost option involving unlocking and cleansing existing tubes; (c) re-alignment of tilted column to improve drying, productivity and quality with a cost option which is neither high nor low to be carried out during the annual shut-down; and (d) re-institute the cone height to improve operating parameters in the drying column and expected to improve productivity and efficiency with a medium cost dependent on the availability of technical information.

In addition to the specific technical changes, there was a recommendation to scrap the old plant and purchase a modern plant. There was however recognition that such a leap is expensive and difficult to implement from local know-how and technology.

The environmental effect of the introduction of the decanter/vacuum filter is improvement in waste handling and reduction of the biological oxygen demand (BOD) while improving efficiency in the raw material usage. The flow meter will reduce water consumption and new pistons will reduce extract losses rated at five litres every 15 minutes, and reduction of lump formation in the spray-drying column. Lump generation was reported reduced by 60 per cent. Clearance of 90 per cent of the lump stock in four months was valued at Z\$1.5 million. Losses are reported also to have been eliminated in extract saving plant at Z\$364 per hour. Restoring manometers have improved pressure monitoring in drying column. Alignment of the column has led to reduction of lump formation. All the above technical improvements have been implemented. Due to lack of information, implementation is still required in the reconstitution of the original height cone, which was expected to reduce lump formation and the replacement of old, plant equipment by new and modern equipment.

In Zimbabwe the national cleaner production centre has been reported to conduct training for graduates to produce environmental auditors or clean production trainers (Mombemuriwo, 1996). Training institutes were also encouraged to introduce cleaner production concepts in their curricula. Links with the University of Zimbabwe to introduce research students on cleaner production has been explored. The national breweries of Zimbabwe have been audited in addition to the sugar refineries.

THE SIGNIFICANCE OF CLEANER PRODUCTION FROM THE FEW CASES IN ZIMBABWE

If we recall the taxonomies from innovation studies (e.g. Freeman and Soete, 1997) what has taken place in the clean production audits can be

characterised to fall largely in the category of incremental technical innovation. Cleaner production options were identified. Feasibility was tested. Financial and economic assessments were undertaken. Equipment modifications to existing plant were suggested and implemented. Certain barriers were noted such as the fact that technical information is unknown to reconstitute an original cone height for reducing coffee lump formation. Most of the technical problems require knowledge for equipment modification and adjustment. When the innovation demands a complete overhaul of old plant equipment it would require overcoming existing conceptual, technical, informational (know-how and knowledge), organisational and economical constraints. The road will be paved to introduce cleaner production systems. But such a radical innovation in turn demands conceptual, policy, institutional and technological synergy and combined action. The cleaner production options would be selected more readily whenever they become enabling to bring about a win-win outcome between environmental benefit and economic profits. In the end, building this double incentive to cleaner production policy requires a national strategy to attain at the same time a sort of double dividend between environmental gain and economic gain. Such a macro-national commitment will be a powerful engine for removing the conceptual resistance to the adoption and diffusion of cleaner production options by industries in Zimbabwe as indeed elsewhere in Africa.

PROBLEMS OF CLEANER TECHNOLOGY TRANSFER INTO AFRICA

The cases selected show exemplification of the difficulties of incorporating cleaner technologies into African firms. The main problem is that the technology comes from the outside (Muchie, 2000a). African countries expect cleaner technology transfer, but actual transfer is not forthcoming. As the Nigerian Government put it, "Available technology in the country appears grossly inadequate to meet with the challenges of implementing Agenda 21 and the programme of transfer of technology is yet to take off fully" (Federal Republic of Nigeria, 1997: 57). What holds for Nigeria may hold for a large number of African countries: available technology is not yet of the cleaner genre; and (b) cleaner technology transfer is yet to take off.

This claim is corroborated with the global trends in R&D levels and FDI flows into Africa. The current trend in Sub-Saharan African countries (SSAs) expenditure of R&D as a proportion of the gross national product (GNP) for the continent as a whole is very low. According to a UNESCO report, the R&D expenditure as a proportion of the gross national product (GNP) for Africa as a whole was a mere 0.28 per cent in 1980, while Asia spent 1.40 per cent of its GNP on R&D, and North America a 2.23 per cent. By 1990 the situation

has worsened in Africa by R&D dropping to 0.25 per cent, while in Asia it had increased to 2.05 per cent and in North America to 3.16 per cent. By 1990 Africa's share of world R&D expenditure constituted only 0.2 per cent of the whole (UNESCO, 1992).

Have African countries begun to increase their R&D expenditure in general and environmental R&D in particular? The concentration of African countries on science and technology seems to have been lower than on other pressing matters. For example, 'of the 925 resolutions passed by the OAU Council of Ministers over the 20-year period 1963–82, a mere 3 per cent dealt solidly with scientific and technological issues (and probably 12.5 per cent with associated scientific and technological matters' (Odhiambo, 1993: 34). Within a single generation, from 1962 to 1988, South Korea's GNP increased from US\$2.3 billion to US\$169 billion, and this was accompanied by a national investment in R&D which grew from 0.24 per cent of the GNP in 1962 to a massive 2.1 per cent in 1988. Taiwan and Thailand are following this same pattern (Brown and Sarewitz, 1991).

Human capital construction has suffered in SSA. It has been reported that total public spending on education in SSA fell in real terms between 1980 and 1988 from US\$11 billion to US\$7 billion. For a sample of 26 countries, this translated into a decline in spending per pupil from US\$133 to US\$89. In much of sub-Saharan Africa, educational expansion has come to a grinding halt completely by 1989. Enrolment declined in primary, secondary and tertiary sectors. The decline of the latter was 66 per cent between 1980 and 1985 (World Bank, 1993). This reduction in financing education has lowered the quality of education across the whole spectrum: supervision, inspection, in-service teacher education, curriculum development, and school health services, school furniture, equipment and physical facilities, (Michael Barratt-Brown, 1995). The region of high economic performance – Hong Kong, Korea and Singapore – attained universal primary education, roughly at the same period in which SSA countries were politically decolonising. Investment on education has been high. For example, Korea's real expenditure per pupil rose by 355 per cent over the 1970–89 period (World Bank, 1993: 43).

Enos (1995) has asked the question of whether structural adjustment has facilitated the increase in R&D in SSA. He has undertaken a study of the impact of structural adjustment on science and technology in Sub-Saharan Africa by studying the national system of innovation of four SSA countries: Ghana, Kenya, Tanzania and Uganda. It is estimated that SSA countries invest roughly 0.5–1 per cent of GDP, and an equivalent percentage on technical education and training (Enos, 1995: 267). Enos suggests that the R&D finance requirement from donors for SSA will be substantial. 'Assistance will be needed for a very, very long time' (Enos, 1995:270).

While Enos was not thinking of environmental R&D, his observation on the need and scale of financial assistance applies equally for generation and transfer of ESTs to SSA.

If we take data on R&D figures from one SSA country – Kenya – the total investment for R&D is about 0.3 per cent of the 1993 GDP of the country. This percentage is below the 0.5 per cent suggested by the International Development Strategy for the Second development Decade achieved by the end of the 1970s. It is also below the usually suggested 1 per cent of GDP on R&D (Kenya government, 1986). IBRD in its African Development Indicators, 1994–1995 said that Kenya spent about US\$11 000 000 in the period 1985–87 on R&D, of which 9.5 per cent is said to have come from the private sector. By 1993, total expenditure on R&D averaged at US\$30 000 000 at a GDP level of US\$9 388 000 000 (IBRD, 1995: 10). In the period of 1985–87 about 70 private firms were undertaking R&D with a total expenditure of US\$951 000 at an average of US\$13 800 per firm. In the same period 21 public institutions spent US\$10 024 000 at an average of US\$455 620 per institution (Nyacet, 1996: 2). Private sector funding of R&D is lower and supplementary to public funding. Linkages between private and public bodies are weak. Institutional and human capacity needs strengthening.

Whereas we have such aggregate figures for R&D expenditure as a percentage of GDP, we do not have a desegregated figure for environmental R&D both as part of gross R&D expenditure or GDP for SSA. Such data will begin to emerge as the environment becomes increasingly integrated in national and regional economic development.

Equally important, the current trend in the absorption of foreign direct investment per unit of GDP shows a less than optimistic trend. In 1970 SSA absorbed 5.2 dollars per \$1 000 of GDP whilst Asia absorbed \$ 2.6 for the same rate of GDP. After 1975 Asia at 3.9 surpassed the African at 3.2 FDI absorption. In 1980 Africa hit a low point of 1 dollar per 1 000 dollars of GDP with Asia at 3.7 dollars per 1000 dollars of GDP. In 1993 Africa picked up to 9.6 dollars per 1 000 dollars of GDP while Asia moved to a double digit 23.1 per 1 000 dollars of GDP (UNCTAD, 1995: 80).

From the above figures, it is not permissible to conclude that no FDI and R&D have been transferred to SSA. What is perhaps accurate is that whatever R&D and FDI were transferred could not be of such a large scale as to bring structural transformation in SSA region's national system of production.

In particular there are a set of specific problems related to SSA's structural weakness, which militate against the development of EST-based capacity and innovation system:

- a. Weakness in technology assessment,
- b. Doubt over SSA early entry to cleaner technologies,

- c. Relevance of foreign assistance, and
- d. Lack of implementation of Agenda 21.

First: the experience of conventional technology transfer has been 'very discouraging in most cases in Africa' (UNCTAD, 1995). It remains to be seen whether the UNCED process will make a difference in persuading companies producing pollution controlling technologies to transfer to African firms and economies. One of the necessary conditions is to change the view by established experts to confine Africa's comparative advantage in the products and processes that utilise 'simple production technologies' (Lall, 1989: 94). The African local techno-industrial environment is said to be unresponsive to more advanced technological activities. According to Lall, 'there exists a general failure of African private enterprise to enter modern industry in a significant way. Of more advanced technical activity – R&D, design, entry into sophisticated engineering fields – there is practically no sign' (Lall, 1989: 101).

Vernon (1989) suggests that developing countries 'that develop a strong internal capacity to search out and evaluate foreign technologies are usually able to acquire the technologies they need on satisfactory terms. Those that fail to search and evaluate, however, can make costly errors'. Technology assessment has emerged as an important discipline whose aim is to evaluate the prospects and risks associated with particular technologies (Clark et al., 1991). Technology assessment is one of the areas that African countries have paid the least attention to (Ruijters, 1996). The tendency has been to rely on technological information from those supplying the technology. In many cases, the ability of the African countries to assess technologies is prejudiced by tied aid and linkages between the suppliers of technology and those providing finance (either as grants, equity capital or loans). Human resource and skill construction to build the capacity for technology assessments and to make effective use of technical knowledge in production, investment, innovation and management are necessary. The goal of competency in technology assessment is to transform the acquired technology to support continuous innovation within the domestic setting.

Second: some commentators have raised doubts on the accessibility of early entry to countries with low skills. They question the early entry into cleaner technologies and argue for incremental and radical innovation improvements. For example, Mytelka (1989: 62) questioned the early entry model for lack of appreciation of the skills needed to internalise cleaner technologies as domestic technological capabilities. She argues that those who generally write on leapfrogging have not sufficiently integrated the need for a mastery of skills required for technology absorption with their emphasis on the transfer of productive capacity. Human resource and institutional competence are necessary to incorporate into development policy

the public knowledge and information that may exist at the early R&D stage. Willingness to transfer cleaner technologies must be matched by ability to internalise it within a country's national system of innovation. Removal of intellectual property and licensing restrictions can make knowledge available, but that does not ensure uptake by the domestic system unless there is adequate capacity to do so. While early entry possibilities may exist despite new restrictions by new intellectual property regimes, SSA uptake is severely constrained by weak human and organisational competencies.

Bell (1994) seemed to ignore the early entry theory altogether and came nearer the Vernon product cycle when he suggests what he thought possible and practicable: improving on incremental innovations rather than expecting transfer of new and cleaner technologies, including the mechanisms and management which might be used to transfer such 'technology'. He advocates 'deepening' the technology transfer content of existing types of 'energy efficiency' by local firms, and 'deepening' the technology transfer content of a much wider range of power sector and industrial investment projects including management training and organisational innovations within the recipient firm. Bell argues for the strengthening of the transnational industrial corporations in order to enhance new forms of alliance and network for technological and managerial learning.

Third: There are also problems between foreign assistance and building national technological capability. Technology transfer can be effective only if it is connected to capability building leading to self-reliance. By the latter is meant the ability of a firm or a country to identify national technological needs and mix local and foreign technology to strengthen the technological accumulation and cumulative capabilities of the country or firm. The real problem is the extent to which the national system of innovation, research, education and skill cohere to promote ESTs to be taken up by local industry. In most African countries, 80–90 per cent of the total recurrent budgets of national R&D institutions is devoted to personnel emoluments. Foreign funding plays a disproportionate role in the organisation and delivery of the research system. For example for Kenya, the ratio of 10:1 describes the research sponsored by foreign sources to the local. In Ivory Coast and Senegal between 30 and 40 per cent of scientists are French nationals (Tiffin and Osotimehin, 1992: 44). The link between Government funding and university research is weak, but it is practically non-existent between private firms and research institutes. Local researchers are severely disadvantaged in research agenda setting with respect of international funders. African Governments are known to discourage local consultants showing preference to consultants from the industrialised countries. A directory by IDRC shows major sources of funding come from OECD based agencies (Tiffin and Osotimehin, 1992). A revealing example of this state of affairs – local

research neglect and international research power – is given by the research on ‘endod’, a soapberry plant.³ Ethiopian scientists started the initial research. Subsequent research involved international assistance and the result has been patented in the U.S.⁴ This was repeated for another rare millet group crop called ‘teff’, which is also patented in the U.S. and grown in Idaho. During the post-Rio period international co-operation should assist in order to make assistance redundant and not in a manner that more assistance would be necessary. Without such changes local research capacity on ESTs and endogenous technological system building will be unavailable for SSA. The pattern of assistance in the form of project aid often makes the foreign consultant acquire learning and domestic actors often fail to acquire new knowledge to make any difference.

Fourth: In the report of the workshop on the transfer and development of environmentally sound technologies, UNCTAD points out further difficulties in accessing technology: ‘There were cases where owners of technology had been unwilling to make technology available to licensees, or had set very high prices on it. At the other end of the scale there were also cases where environmentally superior technologies were more or less freely available, but not transferred to developing countries for lack of an attractive market opportunity’. The report adds, ‘such failures were of particular concern where technologies in question were critical to sustainable development or relevant to global environmental problems’. It was also noted that such failures include intermediate technologies and not just leading edge technologies (UNCTAD, 1994: 23).

There appears to be failures in the technology transfer market. For a variety of reasons the corporations who hold the patent or control of a given technology may or may not transfer it in spite of the existence of Agenda 21’s provisions on technology transfer. Much of the technology transaction takes place among transnational firms, their subsidiaries and associated firms. With or without the provisions on technology transfer from Agenda 21 which their governments may have ratified even on their behalf the corporations would engage in transfer of technology based on their own assessments of the benefit and loss calculation. Transfer of technology is a matter they can choose to engage in or not. There is thus a need to reconcile the good intentions contained in the UNCED process and the reality of how corporations actually carry out technology transactions.

International funds can assist to transfer ESTs which are not being produced in the developing country regions through such schemes as joint-ventures to enhance domestic capability for ESTs production, and to provide organisational-management, training and skill development. However technology procurement through foreign assistance comes with its own specific problems (UNCTAD, 1994: 9). For example, equipment for environmental

protection may not be appropriate to the institutional and human capacity in the recipient countries. There may not be effective demand for ESTs in the receipt countries, which may discourage technology procurement. There may also be a mismatch between the needs of the domestic economy and the ESTs from external sources. There is often weakness in co-ordinating policies for technology procurement and national or regional industrial policies.

These problems tend to be worse in countries where the technological capacity, skills and organisational structure are low. In order to make endogenous a dynamic EST industrial sector, foreign assistance can be used to assist in facilitating the technology from the outside to overcome the domestic barriers to enable its effective utilisation and diffusion. Foreign assistance has to be guided by policy priorities for technology cooperation to stimulate local knowledge by building on the available knowledge and experience of the domestic economy of the recipient countries (UNCTAD, 1994). Technological transfer through cooperation is effective only if it leads to the internalisation of technological capabilities, accumulation and institutional competence and learning inside the domestic social-economy.

Both the prime sources of technology capability and technology transfer, R&D and FDI are low in the aggregate, although the figures may vary in specific African economies. This suggests the scepticism by Nigeria that technology transfer is something that is expected yet to take place in Africa.

The main constraints faced by the SSA region in preventing an uptake of ESTs are related to lack of awareness of the economic benefits of cleaner technologies, lack of knowledge and information about cleaner techniques and technologies and lack of financial resources to purchase imported ESTs. These problems can be overcome provided concerted action by international organisations, national governments and industries is taken. UNIDO and UNEP have jointly created the national clean production centres. These centres have been engaged in local capacity building, information dissemination, training and education, inter-sectoral demonstration projects, creating cooperative arrangements between environment service sectors between developing and developed countries and research on environmentally compatible products (UNIDO, 1995). However many of these centres in Africa remain fuzzy, not connected to the system of knowledge generation, production and public policy management (Muchie, 2000a).

CONCLUSION: THE UPTAKE OF ESTS IN FIRMS AND INDUSTRIAL POLICY

Agenda 21 has stimulated the adoption of ESTs in African firms. From the reports of the cases of cleaner production assessment undertaken by

international consultants, there is incontrovertible evidence that a number of African countries have begun to take cleaner production concepts on board. At the same time the few examples of cleaner production assessments indicates that the selection of the firms is ad hoc and is not governed by any comprehensive national strategy integrating environmental constraints into African industrialisation and poverty reduction game plans. National legislation on environment incorporating the UNCED principles is increasingly being adopted. Investigations of environmental management practices and environmental audits have been undertaken in a number of sectors and firms.

The NCPC concept is novel. And while the idea is to be encouraged, it must be conceptualised within the poverty eradication and ecologically-anchored industrialisation programmes of African states. Technological innovation has to be reconceptualised based on a taxonomy of a green pedigree. The concept of incremental and radical innovation becomes embedded within the environmental paradigm. This new conceptualisation needs to be articulated as part of a national industrial policy. Science, technology and innovation for sustainability become part of the modernisation of Africa. The NCPCs can be re-framed as one of the vehicles for the expression of the eco-industrialisation model of development suggesting a conceptually, institutionally, strategically and policy-level integration of African industrial evolution and environmental security at the same time. The advantage for Africa is that this can be developed as part of the striving to modernise African economy, politics and society.

While there is evidence of EST's activity, what is not clear is how this is conceptualised as part of the drive for the ecological industrialisation of Africa. There is a need for a thorough research to establish the rate of diffusion of cleaner production activities within firms, either by taking firms from more African countries and/or more firms within a few African countries.

The best way forward for African economies is to learn quickly to reveal new comparative advantages on the basis of sustainable development. This translates in the African context as the creation of new industries by drawing from the solar, natural and agricultural resource base of the countries. There is thus a need to undertake more empirical studies on the creation of value-added manufacture of the agrarian sector through ecotechnology capability, innovation and competence building and learning.

The integration of environmental technologies and industrialisation through research, development and capability building may create a new avenue to reveal Africa's comparative advantage in high value-added production in order to unhinge Africa's position in the current frozen international division of labour as exporters of extractive minerals and primary commodities. As written elsewhere in this article: 'The main policy problem

is internal rather than external. It should address the problem of how the SSA region can and should re-organise in order to build knowledge, skills, learning, capabilities, institutions, incentives and resources to address economic and environmental problems at the same time' (Muchie, 2000b: 131–147).

Africa can ditch the 19th–20th centuries' industrial system, if it can create the conditions for ecological industrialisation in the 21st century on a Pan-African scale and scope. Public policy in Africa can focus in marrying environmental technologies to African rich natural resources and make Africa's time for building its future with trade and investment in high value added, cleaner products and services.

NOTES

- 1 Through extensive conversation with UNIDO/UNEP cleaner production consultants specially from those in IMAM, the University of Amsterdam, the author was able to compile the following case in cleaner production assessments in Zimbabwe's firms.
- 2 One US\$ equals Z\$16.
- 3 Endod has become an alternative to Bayluscide (niclosamide) manufactured by Bayer Co. and sold at over US\$30 000 per tonne. Development assistance has recommended its export to other African countries.
- 4 The Ethiopian scientist who undertook the research on endod said: "...the problems of scientific research in Africa include... the reservations of those who find it difficult to accept that good science can come from [Africa]. Even our own Government officials, who rely on foreign assistance and external advice, may be unduly influenced concerning local research" (Lemma quoted in Clark et al., 1991: 34).

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Climate Debt Owed to Africa

What to Demand and How to Collect?

Patrick Bond

SUMMARY

The 'climate debt' that the industries and over-consumers of the Global North owe Africans and other victims of climate change not responsible for causing the problem has accrued by virtue of the North's excessive dumping of greenhouse gas emissions into the collective environmental space. Damage is being accounted for, including the more constrained space the South has for emissions. This historical injustice – and 'debt' – is now universally acknowledged, and reparations plus adaptation finance are being widely demanded. In Copenhagen, the 2009 United Nations summit on climate change witnessed a great deal of theatre over conceptual problems, including who should make emissions cuts and to what degree; should markets be the main mechanism; who owes a climate debt; how much is owed; and how the debt should be collected. The willingness of African heads of state to raise the matter publicly beginning in mid-2009 was notable, but their inability to ensure political solidarity led to the imposition of the Copenhagen Accord on 18 December, in a manner that sets back the cause. Civil society will have to continue working with Latin American governments, especially Bolivia's, to advance this struggle in coming months and years – even though it is in the self-interest of African rulers to join the campaign more forcefully and durably than they did in 2009. Without African government support for the concept, systems of climate debt payment won by civil society designed to bypass the African national state (such as Basic Income Programs) will be ever more attractive.

INTRODUCTION

"The largest share of historical and current global emissions of greenhouse gases has originated in developed countries... [and should be redressed] on the basis of

equity and in accordance with their common but differentiated responsibilities."

– *United Nations Framework Convention on Climate Change, 1992.*

"The sense of guilt or culpability or reparations – I just categorically reject that."

– *Chief US climate negotiator Todd Stern on being asked about climate debt, December 2009 (Spector, 2009).*

"We are not assigning guilt, merely responsibility. As they say in the US, if you break it, you buy it".

– *Bolivian ambassador to the United Nations, Pablo Solon, December 2009 (Solon, 2009).*

Climate damage to Africa will include much more rapid desertification, more floods and droughts, worse water shortages, increased starvation, floods of climate refugees jamming shanty-packed megalopolises, and the spread of malarial and other diseases. The most probable outcome of climate change is, according to the UN Intergovernmental Panel on Climate Change director R.K. Pachauri, 'that there could be a possible reduction in yields in agriculture of: 50 per cent by 2020 in some African countries... In Africa, crop net revenues could fall by as much as 90 per cent by 2100, with small-scale farmers being the most affected' (Pachauri, 2008: 17).

The Climate Change Vulnerability Index, calculated in 2009 'from dozens of variables measuring the capacity of a country to cope with the consequences of global warming', listed 22 African countries out of 28 across the world at 'extreme risk', whereas the United States is near the bottom of the world rankings of countries at risk even though it is the leading per capita contributor to climate change (Agence France Press, 2009).

There is no question that those most responsible should pay reparations, now that there is near-universal awareness of the damage being done by rising greenhouse gas emissions, and by the ongoing stubborn refusal by the rich to cut back. In 1997 at the Kyoto Protocol negotiations, the Global North offered to assist Africa financially through 'Clean Development Mechanism' (CDM) projects, in a context of declining overseas development aid associated with the end of the Cold War. Many African elites agreed, along with once reluctant environmental groups. Popular movements were unaware and uninvolved, and expert opinion was mixed about the efficacy and moral implications. The proponents of carbon trading argued that this would be the least painful – and least resisted – means of capping greenhouse gas emissions and allowing economies to adapt to new carbon constraints.¹

However, by 2010, prospects were not good for the broader carbon markets into which CDMs fit as a small sideline (worth roughly 6.5% of the \$125 billion in 2008 trades, a ratio that probably grew slightly on flat trading

volume in 2009). The share of CDM financing to Africa continued to be disproportionately low, around 3 per cent of all CDM projects (and mostly emanating from South Africa, with its huge emissions and large cadre of environmental technical specialists). Given the dubious prospects for carbon trading already evident in myriad European Union Emissions Trading Scheme credibility crises and price volatility problems – with the 2008-09 ‘value’ of a ton of CO₂ falling from €30 at peak to less than €9 – the question emerged in Africa in 2009: how to get the North to pay its fair share of the costs of Africa’s adaptation bill?

THE CHOICE OF CARBON TRADING VERSUS CLIMATE DEBT

Two answers emerged: stick with CDMs, or shift to climate debt demands (These are not necessarily mutually exclusive, but do reflect a distinct divergence in analyses, strategies, tactics and alliances). The first answer has been most vociferously articulated by two high-profile Africans, former Kenyan deputy environment minister and Nobel Peace Prize laureate Wangari Maathai, and former South African environment minister Marthinus van Schalkwyk. They assumed that the CDM and similar ‘market-based mechanisms’ for financing climate adaptation would continue to underpin global climate policy in the post-Kyoto period. Maathai promoted this position through her own Greenbelt Movement in the expectation that CDMs and emerging proposals for ‘Reducing Emissions from Deforestation and Forest Degradation in Developing Countries’ would reward tree-planting (both her indigenous strategy as well as monocultural timber plantations). She was also the leading proponent of the document ‘Africa speaks up on Climate Change’, which fed into the ‘African Climate Appeal’, which insists upon more CDM finance with fewer strings attached, especially for afforestation, as discussed in more detail below.²

Van Schalkwyk has just as passionately promoted carbon trading, noting in 2006 that ‘The 17 CDM projects in the pipeline in Sub-Sahara Africa account for only 1.7 per cent of the total of 990 projects worldwide. To build faith in the carbon market and to ensure that everyone shares in its benefits, we must address the obstacles that African countries face.’ A year later, at the International Emissions Trading Association Forum in Washington, he argued, ‘An all-encompassing global carbon market regime which includes all developed countries is the first and ultimate aim.’ Van Schalkwyk was nominated by South Africa to be the replacement to Yvo de Boer as UNFCCC director in early 2010.³

Instead, a different answer was to depart from the CDM approach, to criticize market-based strategies as inadequate, and to demand direct

compensation. In mid-2009, the Ethiopian Prime Minister who was appointed to lead the African Union's climate team, Mr Meles Zenawi, began to pursue the latter strategy, insisting on at least \$67 billion/year from the North to Africa to compensate for anticipated damages to Africa alone.

Critics of emissions trading argue that Mr Zenawi was correct to seek a different route, for the carbon market is not working:

- a. the idea of inventing a property right to pollute is effectively the 'privatization of the air', a moral problem given the vast and growing differentials in wealth inequalities;
- b. greenhouse gases are complex and their rising production creates a non-linear impact which cannot be reduced to a commodity exchange relationship (a tonne of CO₂ produced in one place accommodated by reducing a tonne in another, as is the premise of the emissions trade);
- c. the corporations most guilty of pollution and the World Bank – which is most responsible for fossil fuel financing – are the driving forces behind the market, and can be open to possible corruption to attract money into the market even if this prevents genuine emissions reductions;
- d. many of the offsetting projects – such as monocultural timber plantations, forest 'protection' and landfill methane-electricity projects – are known to have negative impacts on local communities and ecologies, and have been contested in part because the carbon sequestered is far more temporary (since trees die) than the carbon emitted;
- e. the price of carbon determined in these markets is unpredictable, having crashed by half in a short period in April 2006 and by two-thirds in 2008, thus making suspect of the idea that there will be an effective market mechanism to make renewable energy a cost-effective investment;
- f. there is a serious potential for carbon markets to become an out-of-control, multi-trillion dollar speculative bubble, similar to exotic financial instruments associated with Enron's 2002 collapse (indeed, many Enron employees populate the carbon markets);
- g. as a 'false solution' to climate change, carbon trading encourages merely small, incremental shifts, and thus distracts attention and focus from a wide range of radical changes needed to be made in materials extraction, production, distribution, consumption and disposal; and
- h. the idea of market solutions to market failure ('externalities') is an ideology that rarely makes sense, and especially not following the

world's worst-ever financial market failure, and especially not when the very idea of derivatives – a financial asset whose underlying value is several degrees removed and also subject to extreme variability – was thrown into question.⁴

The apparent demise of carbon trading in the 2009-10 legislative session of the US Senate made this strategy a losing proposition not only for Africa but also on a global scale. Even without the expected Washington gridlock (mainly as a result of sabotage by powerful fossil fuel interests), carbon trading had crashed on its own terms by March 2010. 'The concept is in wide disrepute', reported the New York Times (25 March 2010), with US Senator Maria Cantwell explaining that 'cap and trade' (the US description) was 'discredited by the Wall Street crisis, the Enron scandal and the rocky start to a carbon credits trading system in Europe that has been subject to dizzying price fluctuations and widespread fraud.'⁵

To be sure, one wing of civil society still endorses carbon trading, in part perhaps because some major institutions and individuals suffer from substantial conflicts of interest as carbon-traders.⁶ Increasingly, carbon trading appears as a 'false solution', in contrast to the alternative financing source for climate damage: the North's payment of its climate debt to the South for excess use of environmental space and for the problems caused in many ecosystems already, and in future when vast eco-social crises are anticipated especially in Africa. What, then, is the character of the 'ecological debt' more broadly, and the climate debt in particular?

DEMANDING ECOLOGICAL AND CLIMATE DEBT REPAYMENT

According to the Quito group Accion Ecologica: 'ecological debt is the debt accumulated by Northern, industrial countries toward Third World countries on account of resource plundering, environmental damages, and the free occupation of environmental space to deposit wastes, such as greenhouse gases, from the industrial countries' (Accion Ecologica, 2000: 1). The term came into professional use in 1992 at the Earth Summit of the United Nations in Rio de Janeiro of 1992, with NGOs promoting the concept through an 'Alternative Treaty'.

An initial voice was the Institute of Political Ecology in Santiago, Chile, and contributed to world consciousness about ChloroFluoroCarbon damage to the ozone layer. A Colombian lawyer, José María Borrero, wrote a 1994 book on the topic, and further research and advocacy was provided by the Foundation for Research on the Protection of the Environment, and then Jubilee South. By 1999 Friends of the Earth International and Christian

Aid agreed to campaign against Ecological Debt, especially in relation to climate damage. In Africa, among the main advocates of Ecological Debt repayment were churches, especially the Economic Justice Network of southern Africa led by Malcolm Damon and Francis Ng'ambi. Other regional initiatives continued, moving to the global stage by 2009. The World Development Movement and Jubilee Debt Campaign (UK) produced a major campaign document in late 2009 (World Development Movement and Jubilee Debt Campaign, 2009), at the same time as an influential article by Canadian journalist/campaigner Naomi Klein in *Rolling Stone* magazine (Klein, 2009).

The leading scientist in the field, Autonomous University of Barcelona's Joan Martinez-Alier (2003: 26), calculates ecological debt in many forms: 'nutrients in exports including virtual water, the oil and minerals no longer available, the biodiversity destroyed, sulfur dioxide emitted by copper smelters, the mine tailings, the harms to health from flower exports, the pollution of water by mining, the commercial use of information and knowledge on genetic resources, when they have been appropriated gratis ('biopiracy'), and agricultural genetic resources.' As for the North's 'lack of payment for environmental services or for the disproportionate use of Environmental Space,' Martinez-Alier criticizes 'imports of solid or liquid toxic waste, and free disposal of gas residues (carbon dioxide, CFCs, etc)'. According to Martinez-Alier (2003: 25):

The notion of an Ecological Debt is not particularly radical. Think of the environmental liabilities incurred by firms (under the United States Superfund legislation), or of the engineering field called 'restoration ecology', or the proposals by the Swedish government in the early 1990s to calculate the country's environmental debt.

The sums involved are potentially vast. As Martinez-Alier puts it, 'tropical rainforests used for wood exports have an extraordinary past we will never know and ongoing biodiversity whose destruction we cannot begin to value'. However, 'although it is not possible to make an exact accounting, it is necessary to establish the principal categories and certain orders of magnitude in order to stimulate discussion... If we take the present human-made emissions of carbon, [this represents] a total annual subsidy of \$75 billion is forthcoming from South to North' (Martinez-Alier, 2003: 28). Leading ecofeminist Vandana Shiva (Shiva, 2005), and former South Centre director Yash Tandon⁷ estimate that wild seed varieties alone account for \$66 billion in annual biopiracy benefits to the US. There are dozens of examples of biopiracy in Africa, according to a 2005 study commissioned by the Edmonds Institute and African Centre for Biosafety.⁸

A partial ecological debt accounting was published by environmental scientists in early 2008, and counted \$1.8 trillion in concrete damages over several decades (Srinivasan et al., 2008). According to co-author Richard Norgaard, ecological economist at the University of California, Berkeley, generated a crucial finding: 'At least to some extent, the rich nations have developed at the expense of the poor, and, in effect, there is a debt to the poor' (Guardian, 21 January 2008). The study included factors such as greenhouse gas emissions, ozone layer depletion, agriculture, deforestation, overfishing, and the conversion of mangrove swamps into shrimp farms, but did not (so far) succeed in calculating other damages, e.g. excessive freshwater withdrawals, destruction of coral reefs, bio-diversity loss, invasive species, and war.

Another route into the intellectual challenge of calculating ecological debt was taken by the World Bank in its estimates of tangible wealth (in the 2006 book, *Where is the Wealth of Nations?*). In addition to resource depletion and rent outflows, there are also other subsoil assets, timber resources, non-timber forest resources, protected areas, cropland and pastureland to account for. The 'produced capital' normally captured in GDP accounting is added to the tangible wealth, but the result of a 'genuine wealth' accounting leaves vast negative adjustments to every African country. With the sole exceptions of Botswana, Mauritius, Namibia, Seychelles and Swaziland, all others have explicitly negative net year-on-year changes once environmental corrections to GDP are made (using 2000 as a sample year) (World Bank, 2006). In sum, notwithstanding the World Bank's conservative counting bias,⁹ Africa shows evidence of net per capita 'wealth' reduction, largely traceable to the extraction of nonrenewable resources that is not counter-balanced by capital investment from firms doing the extraction.

In this context of systemized looting of resources (as even acknowledged by the World Bank), Bolivia at least began the process of making climate debt a concept more broadly understood within the international discourse. That country's submission to the UNFCCC in 2009 made the demand explicitly (Republic of Bolivia, 2009):

The climate debt of developed countries must be repaid, and this payment must begin with the outcomes to be agreed in Copenhagen. Developing countries are not seeking economic handouts to solve a problem we did not cause. What we call for is full payment of the debt owed to us by developed countries for threatening the integrity of the Earth's climate system, for over-consuming a shared resource that belongs fairly and equally to all people, and for maintaining lifestyles that continue to threaten the lives and livelihoods of the poor majority of the planet's population... Any solution that does not ensure an equitable distribution of the Earth's limited capacity to absorb

greenhouse gases, as well as the costs of mitigating and adapting to climate change, is destined to fail.

In addition to Bolivia, the Cumana Declaration was signed by Cuba, Dominica, Honduras (prior to the coup), Nicaragua and Venezuela, and included the argument that developed countries are in an environmental debt to the world because they are responsible for 70 per cent of historical carbon emissions into the atmosphere since 1750. Developed countries should pay off their debt to humankind and the planet; they should provide significant resources to a fund so that developing countries can embark upon a growth model which does not repeat the serious impacts of the environmentally unfriendly industrialization.¹⁰

AFRICA UNITED THEN DIVIDED ON CLIMATE DEBT

How did African governments react to the new narrative around ecological debt? In general, with a few exceptions, the post-colonial leadership of African states has cooperated with those institutions doing the resource extraction and over-utilising Africa's ecological space, in spite of persistent complaints by exploited communities, by workers subject to safety/health violations and exploitation, by environmentalists and by patriotic nationalists. However, finally in mid-2009, the African Union's leadership on climate issues became a force to be reckoned with.

Lesotho had raised the issue of climate debt in UN negotiations, but the highest profile discussion was initiated by Mr Meles Zenawi, who also chaired the New Partnership for Africa's Development (NEPAD) and thus was invited to G20 gatherings along with the South African government. Zenawi's repression of local civil society activists suggested that it might ultimately be counterproductive for Zenawi to lead the climate debt campaign (McLure, 2009). Still, someone from Africa was compelled to express the extreme costs to the continent of the debt, and prior to December 2009, Zenawi played that role.

The African elites could marshal an implied threat: repeating their performance in Seattle in 1999 and Cancun in 2003, when denial of consent in World Trade Organisation negotiations were the proximate cause of the summits' collapse on both occasions. On 3 September 2009, Zenawi issued a strong threat from Addis Ababa about the upcoming Copenhagen conference: 'If need be we are prepared to walk out of any negotiations that threaten to be another rape of our continent' (Ashine, 2009). To gather sufficient power, Zenawi established the Conference of African Heads of State and Government on Climate Change: chairpersons of the AU and the AU

Commission, representatives of Ethiopia, Algeria, the Democratic Republic of Congo, Kenya, Mauritius, Mozambique, Nigeria, Uganda, Chairpersons of the African Ministerial Conference on Environment and Technical Negotiators on climate change from all member states. They met at the AU Summit in Sirte, Libya in July 2009, agreeing that Africa would have a sole delegation to Copenhagen with a united front and demands for compensation. According to AU official Abebe Haile Gabriel, 'Trillions of dollars might not be enough in compensation. Thus there must be an assessment of the impact before the figure.' Added AU head Jean Ping, 'Africa's development aspirations are at stake unless urgent steps are taken to address the problems of climate change. Climate change will fundamentally affect productivity, increase the prevalence of disease and poverty... and trigger conflict and war' (Bond, 2009b: 13).

The most important African negotiator – and largest CO₂ emitter (responsible for more than 40 per cent of the continent's CO₂) – is South Africa (Bond et al., 2009). Aside from ostensibly preventing climate change that could have an especially devastating impact on South Africa, Pretoria's climate negotiators have two conflicting agendas: increasing Northern payments to Africa (a longstanding objective of the New Partnership for Africa's Development, which unsuccessfully requested US\$64 billion per annum in aid and investment concessions during the early 2000s); and increasing South Africa's own rates of CO₂ outputs by around 2030–35, when the Long-Term Mitigation Scenario – South Africa's official (albeit non-binding) climate strategy – would come into effect. Only then are absolute emissions declines offered as a scenario. In the meantime, Pretoria has earmarked more than US\$100 billion for emissions-intensive coal and nuclear fired electricity generation plants due to be constructed during 2010–15, which would amplify Africa's climate crisis, requiring more resources from the North for adaptation.

Thus far, South Africa does not, officially, see itself as a climate debtor, in spite of strong climate debt advocacy by the new Climate Justice Now! In February–April 2010, the World Bank considered and then granted a US\$3.75 billion loan to Eskom primarily for the construction of the world's fourth-largest coal-fired power plant. As explained by environment minister Buyelwa Sonjica in September 2009: 'We expect money. We need money to be made available... we need money as of yesterday for adaptation and mitigation' (South African Press Association, 2009a). South African negotiators also led the G77, and are on record from August 2009 demanding that 'at least 1 per cent of global GDP should be set aside by rich nations' so as, according to one report, to help developing countries conduct research, improve flood control, protect their coastlines, create seed banks and take other steps to cope with the severe storms and droughts linked to climate change. The money could also help poor countries obtain technology to

reduce their carbon emissions. Alf Wills, a top South African environmental official, summed up the position going into Copenhagen: 'No money, no deal' (South African Press Association, 2009b).

The effect of this rhetoric appeared to entail certain immediate concessions. In September 2009, the European Union announced it would begin paying its climate debt, but only up to US\$22 billion annually to fund adaptation, roughly 1/7th of what EU environment commissioner Stavros Dimas observed would be required by 2020 (\$145b). Some of that would be subtracted from existing aid. The EU damage estimates were considered far too conservative, as China's mitigation and adaptation costs alone would be US\$438 billion annually by 2030, according to Beijing. According to one report, the EU view is that emissions trading should be the basis of 'much of the shortfall': 'The international carbon market, if designed properly, will create an increasing financial flow to developing countries and could potentially deliver as much as €38bn per year in 2020' (Chaffin and Crooks, 2009: 24).

Because this offer was widely judged as inadequate, Zenawi carried out a trial run of his walk-out threat just prior to Copenhagen, in November 2009 at a Barcelona UNFCCC meeting. Sufficient concessions were not on the table, so his technical negotiators registered a protest. However at the crucial moment in Copenhagen, during the final week when heads of state would arrive to negotiate a new protocol, Zenawi diverted his own flight from Addis Ababa via Paris, where he met French premier Nicolas Sarkozy. Shortly thereafter, he announced the halving of Africa's climate debt demands (Vidal, 2009). According to Mithika Mwenda of the Pan African Climate Justice Alliance, this act had the effect of 'undermining the bold positions of our negotiators and ministers represented here, and threatening the very future of Africa... Meles wants to sell out the lives and hopes of Africans for a pittance. Every other African country has committed to policy based on the science' (Reddy, 2009: 1).

On 17 December, US Secretary of State Hillary Rodham Clinton offered what appeared to be a major concession (Clinton, 2009: 1):

... in the context of a strong accord in which all major economies stand behind meaningful mitigation actions and provide full transparency as to their implementation, the United States is prepared to work with other countries toward a goal of jointly mobilizing \$100 billion a year by 2020 to address the climate change needs of developing countries. We expect this funding will come from a wide variety of sources, public and private, bilateral and multilateral, including alternative sources of finance.

Yet there was no firm line-item in the US budget to this end, just a promise (the US had regularly broken similar aid promises in the past, and at the

same time the US President Barack Obama was cutting back AIDS medicines funding to Africa). The private sources of finances alone could easily exceed US\$100 billion, with CDMs at the time in excess of 6 per cent of the US\$125 billion emissions markets. If, as predicted, the size of the 2020 carbon market reached US\$3 trillion, it would take just 3.3 per cent dedicated to CDMs to reach the US\$100 billion target. So given the private sourcing and likelihoods of loans not grants, Clinton's offer could readily be rejected as meaningless.

The following day, President Barack Obama arrived and at the end of a long negotiating period, persuaded leaders of the BASIC countries – Brazil, South Africa, India and China – to sign the Copenhagen Accord at literally the climate summit's last minute. The 18 December deal followed extremely harsh police repression against nonviolent protesters outside the Bella Center. Inside, Denmark's conservative ruling party leaders set up a 'Green Room' process where 26 countries were cherry-picked to represent the world. When even that small group deadlocked – allegedly due to Chinese intransigence and the overall weak parameters set by the US, the five leaders – Obama, Lula da Silva, Zuma, Manmohan Singh, and Wen Jiabao, attempted a face-saving last gasp. Instead of 350 parts per million (ppm) of carbon in the atmosphere as 'required by science' (as the popular advocacy phrase goes), the Copenhagen Accord signatories promised 15 per cent emissions cuts from 1990 levels by 2020, which could translate into a 10 per cent increase once carbon trading and offset loopholes are factored in. The result would be 770 ppm by century's end, at least a 3.5 C increase, which scientists say will certainly destroy the planet. Moreover, there were no clear sources of financing nor explicit commitments to pay the North's climate debt, which by then was being estimated at US\$400 billion per year by 2020 (World Development Movement, 2009). Moreover, the Accord departed from Kyoto Protocol and Bali Action Plan principles, which set out more ambitious targets for richer than for poorer countries. And the Accord contains no legally binding components or compliance mechanisms.

Most significant was Obama's refusal to lead the North to make 45 per cent emissions cuts and offer payment of the climate debt, and instead engage in a process of leadership so flawed that 350.org leader Bill McKibben charged that 'he blew up the United Nations' (McKibben, 2009). Economist Jeffrey Sachs also accused Obama of abandoning 'the UN framework, because it was proving nettlesome to U.S. power and domestic politics. Obama's decision to declare a phony negotiating victory undermines the UN process by signaling that rich countries will do what they want and must no longer listen to the "pesky" concerns of many smaller and poorer countries.' The idea that the UN is too unwieldy for climate talks surfaced repeatedly in subsequent weeks. The Accord is 'insincere, inconsistent, and unconvincing,'

Sachs continued, 'unlikely to accomplish anything real. It is non-binding and will probably strengthen the forces of opposition to emissions reductions.' Moreover, Clinton's 'announcements about money a decade from now are mostly empty words. They do not bind the rich countries at all' (Sachs, 2009: 1). As Naomi Klein summed up, the Accord is 'nothing more than a grubby pact between the world's biggest emitters: I'll pretend that you are doing something about climate change if you pretend that I am too. Deal? Deal' (Klein, 2009: 1). George Monbiot compared Copenhagen in 2009 to the 1884-85 Berlin negotiations known as the 'Scramble for Africa,' which divided and conquered the continent (Monbiot, 2009). The African Union was twisted and u-turned to support Zuma's capitulation by Zenawi. Even on its own terms, the Copenhagen Accord failed, missing its first deadline, on 31 January 2010, for signing on and declaring cuts for carbon emissions, leaving UN climate chief de Boer to concede that deadlines were 'soft'.¹¹

Several countries had insisted on climate debt as a negotiating framework even before Copenhagen, including Venezuela, Paraguay, Malaysia and Sri Lanka. But in Africa, only Sudan stood out, partly because its UN Ambassador, Lumumba di-Aping, had such a visible role as G77 chief negotiator. At one point, when briefing civil society a week before the fatal Copenhagen Accord deal, he 'sat silently, tears rolling down his face,' according to a report, and then said, simply, 'We have been asked to sign a suicide pact.' For much of the continent, said Di-Aping, 2 degrees C globally meant 3.5 degrees C: 'certain death for Africa', a type of 'climate fascism' imposed on Africa by polluters, in exchange for which the Third World would get a measly US\$10 billion per year in 'fast track' funding, although 'US\$10 billion is not enough to buy us coffins'. Agreeing with leading US climate scientist James Hansen, the Copenhagen deal on offer was 'worse than no deal', said Di-Aping, concluding, 'I would rather die with my dignity than sign a deal that will channel my people into a furnace.' As for the main negotiator, he had this prophesy: 'What is Obama going to tell his daughters? That their [Kenyan] relatives' lives are not worth anything? It is unfortunate that after 500 years-plus of interaction with the West we [Africans] are still considered "disposables"' (Welz, 2009).

CIVIL SOCIETY UPS THE ANTE

Against malevolent states and industries addicted to fossil fuels, there usually arises opposition from civil society. But between a relatively small number of environmental NGOs and other organisations, there are important strategic divisions on how to tackle climate change, whether to address climate debt and what to do about carbon trading. For example, the network

headed by Wangari Maathai (based in Nairobi and Addis Ababa) offered a supportive statement on reform of CDMs and did not mention climate debt in a mid-2009 document:

African governments should ensure that there is equity in geographical distribution of CDM projects and that this is entrenched in the international policy process. They should negotiate for the requirement of up front funding of CDM projects to be waived for many African countries who cannot afford it. The appeal calls upon African countries to embark on the development of CDM capacities and projects including capacity building and development of centers of incubation for CDM projects. African governments should explore possibilities of accessing grants to provide upfront funding for CDM projects and also project development and financing through bilateral arrangements (Maathai, 2009: 4).

Maathai criticised three existing funds – the Special Climate Change Fund, the Least Developed Countries Fund and the Bali Adaptation Fund – because these funds have not been able to address concerns of African countries on adaptation, namely: access, adequacy and equitable geographical distribution. The funds are largely inadequate and inappropriately structured; currently relying on a 2 per cent levy on CDM projects. Access to the funds has been made difficult, among others, by bureaucratic bottlenecks of the Global Environmental Fund and the World Bank. This problem has been diagnosed but the position of African governments on their preferred way forward remains vague. Lastly, the funds are structured in a way that replicates many structural problems manifest in the CDM, resulting in eschewed access in favour of stronger economies from developing countries (Maathai, 2009).

Instead of requesting more CDM carbon trading funds, many more civil society groups instead insisted on raising climate debt as the optimal financing route. In August 2008, Africa chapters of Jubilee South converged in Nairobi to debunk limited ‘debt relief’ by Northern powers and to plan the next stage of financial campaigning. Nairobi-based Africa Jubilee South co-coordinator Njoki Njehu concluded, ‘Africa and the rest of the Global South are owed a huge historical and ecological debt for slavery, colonialism, and centuries of exploitation’ (Bond and Brutus, 2008: 1).

In subsequent months, across the world, increasing numbers of social movements led by indigenous peoples explicitly demanded climate debt repayment. The Anchorage Declaration by indigenous people from the Arctic, North America, Asia, Pacific, Latin America, Africa, the Caribbean and Russia issued a statement calling ‘on the UNFCCC to recognize the historical and ecological debt of the Annex 1 countries in contributing to greenhouse gas emissions. We call on these countries to pay this historical debt’ (Indigenous

Peoples' Global Summit on Climate Change, 2009). A major Trade Union Conference of the Americas (albeit without participation from the US and Canada) insisted that 'Climate justice will only be reached when the Rich States of the North recognize this environmental debt, which also entails a drastic and urgent reduction of their contaminating emissions, the provision of funds for poor countries for climate change mitigation and adaptation processes, and the transfer of 'clean' technologies to the global south for the development of environmentally sustainable productive processes'.¹²

And in Kenya, the Pan African Climate Justice Alliance of 63 NGOs argued:

for their disproportionate contribution to the causes of climate change – denying developing countries their fair share of atmospheric space – the developed countries have run up an 'emissions debt'. These excessive emissions, in turn, are the principal cause of the current adverse effects experienced by developing countries, particularly in Africa. For their disproportionate contribution to the effects of climate change – causing rising costs and damage in our countries that must now adapt to climate change – the developed countries have run up an 'adaptation debt'. Together the sum of these debts – emissions debt and adaptation debt – constitutes the climate debt. Proposals by developed countries in the climate negotiations, on both mitigation and adaptation, are inadequate. They seek to pass on the costs of adaptation and mitigation, avoiding their responsibility to finance climate change response efforts in Africa. They also seek to write-off rather than reduce their emissions and continue their high per-capita emissions. This would deepen their debt and deny atmospheric space to the developing countries like ours, which would be asked to crowd into a small and shrinking remainder. We therefore call on developed countries to fully, effectively and immediately repay the climate debt they owe to African countries.¹³

Also in Nairobi at the same time, the Africa Peoples Movement on Climate Change pronounced (2009: 1):

... The people of Africa, as well as other developing nations are creditors of a massive ecological debt; This ecological debt continues to accrue today through the continued plunder and exploitation of Africa's resources, its people, labor, and economies;... We reject the principle and application of Carbon Trading, which is a false solution based on inventing a perverse property right to pollute. A property right to air; ... We support the call by African leaders for reparations on Climate Change and support the initiative of the upcoming AU ministers of environment meeting and call for African governments to embrace more people centered alternatives for the African people..

Another node of ecological debt organising was the World Council of Churches (WCC), whose Central Committee was lobbied for years by a senior staffer (and former Tanzanian Council of Churches secretary) Rogate Mshana, and finally adopted a formal statement in September 2009 on the North's 'deep moral obligation to promote ecological justice by addressing our debts to peoples most affected by ecological destruction and to the earth itself.' It is useful to consider the WCC's analysis because it does not stop at the debt, but attacks the mode of production itself (World Council of Churches, 2009: 1):

We call for the recognition, repayment and restitution of ecological debt in various ways, including non-market ways of compensation and reparation that go beyond the market's limited ability to measure and distribute... This warrants a re-ordering of economic paradigms from consumerist, exploitive models to models that are respectful of localized economies, indigenous cultures and spiritualities, the earth's reproductive limits, as well as the right of other life forms to blossom. And this begins with the recognition of ecological debt.

The most extensive statement from civil society had more than 230 supporters, and was circulated by Action Aid, Africa Action and the Third World Network during 2009. Excerpts included these demands:

- i. For their disproportionate contribution to the causes and consequences of climate change, developed countries owe a two-fold climate debt to the poor majority;
- ii. For their excessive historical and current per person emissions – denying developing countries their fair share of atmospheric space – they have run up an 'emissions debt' to developing countries;
- iii. For their disproportionate contribution to the effects of climate change – requiring developing countries to adapt to rising climate impacts and damage – they have run up an 'adaptation debt' to developing countries; and
- iv. Together the sum of these debts – emissions debt and adaptation debt – constitutes their climate debt, which is part of a larger ecological, social and economic debt owed by the rich industrialized world to the poor majority.

Honoring these obligations is not only right; it is the basis of a fair and effective solution to climate change. Those who benefited most in the course of causing climate change must compensate those who contributed least but bear its adverse effects. They must compensate developing countries for the two-fold barrier to their development – mitigating and adapting to

climate change – which were not present for developed countries during the course of their development but which they have caused... As the basis of a fair and effective climate outcome, we demand they:

- Repay their adaptation debt to developing countries by committing to full financing and compensation for the adverse effects of climate change on all affected countries, groups and people;
- Repay their emissions debt to developing countries through the deepest possible domestic reductions, and by committing to assigned amounts of emissions that reflect the full measure of their historical and continued excessive contributions to climate change; and
- Make available to developing countries the financing and technology required to cover the additional costs of mitigating and adapting to climate change, in accordance with the Climate Convention.¹⁴

These demands were largely ignored (or explicitly rejected) by state officials, of course, as epitomized by Todd Stern's reaction (see above). Hence the Copenhagen Summit's delegitimised Accord was, from many of the civil society groups' perspective, not actually a disastrous outcome, since they arrived with no viable expectations of progress on either emissions cuts, decommissioning the carbon markets or achieving climate debt repayments. Instead, it represented a chance to firm up demands for future negotiations, including bilateral ones. The process of civil society consolidation also entailed making a distinct break from the emerging market economies whose own fossil-fuel expansion strategies would challenge the physical limits of carbon sinks.

As a result, the BASIC climate signatories soon faced opposition from within. For example in India, Centre for Science and Environment director Sunita Narain argues that her government's negotiators are the same people who would stymie any real action on environmental improvement in the country (Narain, 2010: 1):

They will oppose fuel efficiency standards, tax on big cars, or tough penalties for polluters. But they will still talk glibly about low-carbon economies. They will of course, dismiss out of hand, any discussion on the need for 'radical' and out-of-the-box solutions for equity and sustainability. These, they will tell you, are mere evangelical thoughts of some fringe activists. The men think and act differently. These are the promoters of the Accord in India. And I believe they do so, because for them, firstly, the Accord provides the perfect solution – talk big about change, but do little at home. The U.S. has provided a perfect formula – it promises us the right to pollute, because it wants to legitimize its own pollution. Secondly, it promises that we can get a place on the high table of polluters. And as powerful

conspirators this will mean that we need to do little ourselves, but instead push the price of change on the less favored – the poor of India or the poor anywhere else in the world. It's an open offer to protect, not our right to development as we have been demanding – the rich countries pay for our transition to low-carbon economies. But a simpler proposition: we give you the right to pollute (at least for now). The other proposition is equally seductive. To the countries, which are not yet polluters (from Ethiopia to Maldives), the Copenhagen Accord says we will give money to keep you pliant and agreeable. This is why the Accord promises some fictional money to poor vulnerable countries. It's a perfect formula, designed to please all. There is only one hitch: we will all have to forget the climate change crisis and the hazards and impacts that will grow.

South African critics such as groundWork and Earthlife Africa made similar statements about Pretoria's delegation. The crucial conflict was over South Africa's vaguely-promised 34 per cent emissions cut below anticipated 2020 levels, even though the Long-Term Mitigation Scenario (LTMS) acknowledged that absolute decline would only begin after 2030. Tristen Taylor of Earthlife Africa requested details and after two weeks of delays, learned that the 34 per cent cut promise was from a 'Growth Without Constraint' (GWC) scenario within the LTMS. According to Taylor, 'GWC is fantasy, essentially an academic exercise to see how much carbon South Africa would produce given unlimited resources and cheap energy prices.' Officials who authored the LTMS had already conceded that GWC was 'neither robust nor plausible' eighteen months earlier. This led Taylor to conclude, 'The SA government has pulled a public relations stunt.'¹⁵

In contrast to the BASIC countries and the erratic African Union, civil society groups committed to climate debt, found they had an extremely enthusiastic ally in the Bolivian government. Evo Morales insisted that two additional factors be added to the existing three components of climate debt calculations (the costs of emissions, of foregone development and of adaptation to climate damage): the notions of a 'migration debt' and a debt to nature. This, as Nicola Bullard recounts, would be compensated by dropping restrictive migration practices and treating all humans with dignity, and finally, the debt to Mother Earth. Ultimately, the only way that the debt can be repaid is by ensuring that the historic relations of inequality are broken once and for all and that no 'new' debt will accumulate. This requires system change, both in the North and in the South. That is why climate debt is such a subversive idea (Bullard, 2010).

The Bolivians' main proposals were a 'Universal Declaration of Mother Earth Rights' (with a binding 'Climate Justice Tribunal' to punish violators), a formal compensation mechanism for climate debt, and a 'World People's Referendum on Climate Change' to short-circuit the multilateral fora which

were clearly dysfunctional. Some of the details subsequently worked out in conjunction with civil society in late April 2010 drove the debate forward in significant ways. The Working Group on Climate Debt argued as follows: Climate debt is an obligation of compensation that is generated because of the damage done to Mother Earth by the irrational emissions of greenhouse gases. The primary responsible for these irrational emissions are the so-called 'developed countries', inhabited by only 20 per cent of the world population, and which emitted 75 per cent of historical emissions of greenhouse gases.

These states, which stimulated the environmentally unfriendly development model, are responsible for climate debt, but we should not forget that within these states, there live poor and indigenous peoples who are also affected by this debt. The responsibility for the climate debt of each developed country is established in relation to the level of emissions, taking into account the historically emitted amount of tons of carbon per capita (Working Group on Climate Debt, 2009).

The Working Group made suggestions for payment as follows: (i) The re-absorption [of emissions] and cleaning the atmosphere by developed countries; (ii) Payment in technology (eliminating patents) and in knowledge according to our worldview for both clean development and for adaptation to developing countries; (iii) Financing; (iv) Changes in immigration laws that allow us to offer a new home for all climate migrants; and (v) The adoption of the Declaration on the Mother Earth's Rights.

An additional Working Group on Climate Finance provided a document with further details and even more audacious demands: The scale of existing financial resources currently allocated to developing countries parties for addressing climate change plus the Copenhagen Accord proposal to mobilise (US\$10 billion per year between 2010 and 2012, and up to US\$100 billion by 2020 annually – which represents only 0.8% to 8% of developed countries' national defense budgets, respectively) remains very inadequate.

Developed country parties must commit at least 6 per cent of their annual GDP for climate finance in developing countries. The viability of mobilising this amount of finance is evident – developed countries spend an equivalent amount each year on national defense. In addition, developed countries have mobilised trillions of dollars (equivalent to 5 times the 6% GDP proposed) to bail out failed banks and speculators. This is a question of political will, and the priority given to effectively combating climate change and protecting Mother Earth.

The finance required must be provided from public sources, and must be new and additional to ODA, to bilateral assistance, and to funds flowing outside the UNFCCC. Any funding provided outside the UNFCCC will not be regarded as meeting the commitments of developed country parties under the Convention.

The carbon market shall be eliminated as source of financing, because its environmentally unfriendly logic promotes the paradox that those actors who will benefit most, are the same actors who have most harmed the environment. In addition, market mechanisms allow developed countries to evade their commitments to reduce emissions, while at the same time benefitting economically from the climate crisis. Moreover, this model impedes the equitable distribution of resources, can not guarantee a predictability flow of resources at scale, nor the timely availability or direct access to financing for those most affected.

Financing for climate change must be delivered as grants, understood as a part of the reparations for climate debt between parties. Loans cannot be considered as fulfilment of financial commitments. In the same way climate financing does not signify a donor/recipient relationship between developed and developing countries. All Annex 1 funding allocated to military purposes and subsidies for fossil fuel producers shall be redirected to climate change (Working Group on Climate Finance, 2009).

The Working Group also called for funding to be routed through the UNFCCC, 'replacing the Global Environment Facility and its intermediaries such as the World Bank and the Regional Development Banks.' A further suggestion was that 'The financial mechanism must respect the sovereign control of each country to determine the definition, design, implementation of policy and programmatic approaches to climate change.' As for timing, 'The financial mechanism shall be defined and approved at COP16, and be made operational at COP17' (Working Group on Climate Finance, 2009: 2).

These documents were based upon visionary, radical civil society demands that had emerged over the prior months and years. Some earlier, very ambitious demands – such as the end of apartheid or access to AIDS medicines – were only won after years of struggle, after initially appearing equally audacious and unrealistic. The short term, however, did not offer any genuine potential for the North paying its climate debt. Moreover, because of the influence of big capital and pro-market ideology on Northern governments in the Kyoto process to date, not only will emissions continue rising, carbon trading will not be dropped as a central EU and US strategy. As a result, critique of establishment strategies will become more common, and in turn will force serious advocates of environmental justice to raise important strategic issues about how to get the North to repay the climate debt.

HOW SHOULD THE DEBT BE REPAYED?

Assuming it was possible to wring a commitment from wealthier states, existing North-South redistributive processes have proven to be ineffectual.

Northern foreign aid to the South goes only a small way towards ecological debt repayment. It is a far lower sum (and falling) than military spending (which is rising), and in any case 60 per cent is 'phantom aid', according to the Johannesburg-based agency Action Aid (Action Aid, 2005). Aid is also a tool of imperialism. Other North-South payments to Africa are yet more dubious, including the debt relief promised in 2005. In spite of enormous hype at the Gleneagles G8 meeting, the International Monetary Fund calculates that while lowest-income African countries' debt stock fell in recent years, their actual debt repayments remained stable from 2006-08 and then increased 50 per cent in 2009 as a percentage of export earnings (International Monetary Fund, 2009). So although there was some debt cancellation, it was on debt that could be considered unrepayable. Meanwhile, debilitating debt servicing charges for low-income African countries still prevented both local capital accumulation and provision of social services, much less financing for climate change adaptation.

There are important debates about who should pay what share. But in general, it is important to note that ecological debt results from the unsustainable production and consumption systems adopted by elites in the Northern countries, which are to some extent generalised across the Northern populations. Hence even poor and working-class people in the North, often through no fault of their own, are tied into systems of auto-centric transport or conspicuous consumption, which mean that they consume far more of the Earth's resources than do working-class people of the South.

As a result, some climate campaigners, including the Heinrich Boell Stiftung of Germany's Green Party, have called for 'Greenhouse Development Rights' (GDRs) as a solution, including a per capita 'right to pollute' (and to trade pollution rights). The bigger questions which GDRs pose are whether environmental justice can be measured merely in terms of formal 'equality'; whether environmental justice is instead historical, political-economic, and grounded in social struggles of those adversely affected; and in turn, whether environmental justice should not aim higher, for a broader, deeper eco-social transformation? The GDR approach may foreclose these questions by reducing the challenge to incremental reformism. When it comes specifically to GDRs as a methodology for calculating debt liabilities and beneficiaries, Larry Lohmann of The Cornerhouse (a British development institute) critiques the model's tacit endorsement of a long-discredited concept of 'development' that condescendingly sees 'resilience' as 'far beyond the grasp of the billions of people that are still mired in poverty', and that singles out for special climate blame 'subsistence farming, fuel wood harvesting, grazing, and timber extraction' by 'poor communities' awaiting Northern tutelage in capital flows, social networking, carbon trading and methods for holding policymakers accountable.¹⁶

Is a rights-based approach to environmental services preferable, as a strategy for demanding and properly redistributing ecological debt payments from North to South? South Africa's promises of 'Free Basic Services' (including water and electricity) were not delivered, contributing to the country's standing as having among the highest per capita social unrest in the world. Attempts to gain justice for Soweto residents deprived of water, via taking water pricing through the court system (as high as the Constitutional Court in September 2009) proved extremely frustrating (Bond, 2010).

Juridicial approaches to ecological debt may not be optimal, although interesting precedents have emerged. In November 2008 a San Francisco court began considering an ecological debt and reparations lawsuit – under the Alien Tort Claims Act – filed by Larry Bowoto and the Ilaje people of the Niger Delta against Chevron, for involvement in 1998 murders reminiscent of those that took the life of Ken Saro-Wiwa and eight other Ogoni leaders on 10 November 1995. The first judgments went against Bowoto et al. but appeals are in process. In June 2009, Shell Oil agreed in a similar lawsuit to an out-of-court settlement with reparations payments of \$15.5 million. Although representing just four hours' worth of Shell profits, it was considered a crucial step in establishing liability and disincentivising corporate exploitation of people and nature. In late 2009, further reparations lawsuits were expected in the New York Second District Court by victims of apartheid who initially requested \$400 billion in damages from US corporations which profited from South African operations during the same period. Supreme Court justices had so many investments in these companies that in 2008 they bounced the case back to a lower New York court to decide, effectively throwing out an earlier judgment against the plaintiffs: the Jubilee anti-debt movement, the Khulumani Support Group for apartheid victims, and 17 000 other black South Africans. When Judge Clara Scheindlin replaced the late John Sprizzo, the case suddenly was taken seriously and in March 2009 moved a step closer to trial when she rejected the corporations' attempt to have it dismissed (Bond and Sharife, 2009).

Beyond these kinds of tort actions, will courts start declaring climate-related ecological debt a valid concept? Environmental rights to protection from climate change were explored in a court case filed by Friends of the Earth, Greenpeace and the cities of Boulder, Colorado, Arcata, Santa Monica and Oakland in California, against the US Export- Import Bank and Overseas Private Investment Corporation. The latter had invested, loaned or insured \$32 billion in fossil fuel projects from 1990–2003 without regard to the US National Environmental Policy Act (NEPA). At present, only US cities have formal standing to sue for damages from climate change under NEPA, in the wake of a 2005 federal ruling. The out-of-court-settlement in February

2009 meant that the defendants will in future incorporate CO2 emissions into planning, but there are prospects for further suits that extend into identification and payment of damages (Friends of the Earth, 2009).

There are quite obvious limits to prospects for court relief under the Alien Tort Claims Act or NEPA, the two most advanced areas. Hence it would be consistent for climate justice activists to proceed with more immediate strategies and tactics. As Al Gore expressed it in 2007, 'I can't understand why there aren't rings of young people blocking bulldozers and preventing them from constructing coal-fired power plants' (Kristoff, 2007: 23). Arguing that 'Protest and direct action could be the only way to tackle soaring carbon emissions,' the US National Aeronautic and Space Administration's leading climate scientist, James Hansen, 'The democratic process is supposed to be one person one vote, but it turns out that money is talking louder than the votes. So, I'm not surprised that people are getting frustrated. I think that peaceful demonstration is not out of order, because we're running out of time' (Adam, 2009). Hansen himself participated in direct action in 2009, demonstrating at coal-fired power plants in Coventry, England and West Virginia (where at the latter site he was arrested), as well as at a pro-coal and pro-carbon trading environmental NGO in late 2009.

However, the most effective examples of direct action come from the Global South, especially the Niger Delta. In January 2007, at the World Social Forum in Nairobi, many other groups became aware of this movement thanks to eloquent activists from the Delta, including the Port Harcourt NGO Environmental Rights Action (ERA). In separate disruptions of production (including armed interventions); the Movement for the Emancipation of the Niger Delta prevented roughly 80 per cent of the country's oil from being extracted, although a cease-fire was called in mid-2009 (Mistilis, 2009). The strategy is consistent with the grassroots, coalface and fenceline demands of civil society activists in the Oilwatch network (headquartered at ERA) to leave the oil in the soil, the coal in the hole, the tar sand in the land. Activists from Accion Ecologica popularised this approach in their struggle to halt exploitation of the oil beneath the Yasuni Park in the Ecuadoran Amazon. The German state development agency GTZ conceded to a \$50m/year grant (although Yasuni may become a pilot carbon trading case unless Ecuadoran environmental and indigenous rights activists can resist) (Gallagher, 2009).

Finally, there arises a question of how, if such direct action pressure permits climate debt to become part of Northern elite climate concessions, the debt repayments might be best distributed. It became clear to many civil society groups in recent decades that post-colonial African governments were too easily corrupted, just as were United Nations and aid (and even International NGOs) bureaucracies.

One solution to the payment distribution problem appeared in 2009: the idea of simply passing along a monthly grant – universal in amount and access, with no means-testing or other qualifications – to each African citizen via an individual ‘Basic Income Program’ payment. According to *Der Spiegel* correspondent Dialika Krahe, the village of Otjivero, Namibia is an exceptionally successful pilot for this form of income redistribution (Krahe, 2009: 3–5):

It sounds like a communist utopia, but a basic income program pioneered by German aid workers has helped alleviate poverty in a Namibian village. Crime is down and children can finally attend school. Only the local white farmers are unhappy...‘This country is a time bomb,’ says Dirk Haarmann, reaching for his black laptop. ‘There is no time to lose,’ he says, opening documents that contain numbers he hopes will support his case. Haarmann and his wife Claudia, both of them economists and theologians from Mettmann in western Germany, were the ones who calculated the basic income for Namibia. And both are convinced that ‘this is the only way out of poverty.’ ... ‘The basic income scheme,’ says Haarmann, ‘doesn’t work like charity, but like a constitutional right.’ Under the plan, every citizen, rich or poor, would be entitled to it starting at birth. There would be no poverty test, no conditions and, therefore, no social bureaucracy. And no one would be told what he or she is permitted to do with the money.

In a country like Namibia, says Haarmann, ‘a basic income would achieve what conventional development aid could never do: provide a broad basis for human development, both personal and economic’ (Krahe, 2009: 5).

First priority would be to supply a Basic Income Program to Africans who live in areas most adversely affected by droughts, floods or other extreme weather events. Logistically, the use of Post Office Savings Banks or rapidly-introduced Automated Teller Machines would be sensible, although currency distortions, security and other such challenges would differ from place to place. The Namibian case has much to recommend it, in part because it among the driest sites in Africa.

CONCLUSION

The climate debt strategy ultimately chosen by African elites and civil society campaigners alike, would ideally address the burning problem of how to ensure that the greenhouse gas ‘polluters pay’ in a manner that first, compensates their climate change victims; second, permits transformation of African energy, transport, extraction, production, distribution, consumption and disposal systems; and third, in the process assures the ‘right to development’ for Africa in a future world economy constrained by emissions caps.

Extremely radical changes will be required in all these activities in order not only to ensure the safety of the species and planet, but also that Africans are at the front of the queue for long-overdue ecological and economic compensation, given the North's direct role in Africa's environmental damage. The contemporary argument for climate debt to be paid is simply the first step in a long process, akin to decolonization, in which the master – the polluting Global North (BASIC included) – must realise that not only is it time to halt the reliance on fossil fuels, but having 'broken' the climate (as Pablo Salon puts it), it is their responsibility to foot the clean-up bill.

NOTES

- 1 Market mechanisms – especially carbon trading and offsets – allow corporations and governments generating greenhouse gases to seemingly reduce their net emissions. They can do this, thanks to the Kyoto Protocol, by trading for others' 'certified emissions reductions' (e.g. CDM projects in the Third World) or emissions rights (e.g. Eastern Europe's 'hot air' that followed the 1990s economic collapse). The pro-trading rationale is that once property rights are granted to polluters for these emissions, even if given not auctioned (hence granting a generous giveaway), a 'cap' can be put on a country's or the world's total emissions. It will then be progressively lowered, if there is political will. So as to minimize adverse economic impact, corporations can stay within the cap even by emitting way above it, by buying others' rights to pollute. But this would lead to a more efficient adaptation of economies to pressures associated with a carbon tax.
- 2 Maathai's main institutional ally and funder have been the Forum for Environment, Ethiopia and the Heinrich Boell Foundation (Ethiopia).
- 3 See Van Schalkwyk (2007a, 2007b).
- 4 The analysis generated by Larry Lohmann is probably the most sophisticated, e.g., see Lohmann (2006, 2009a, 2009b, 2009c, 2009d, and 2010). In addition, I have written about the choice between carbon markets and climate debt in Bond (2009).
- 5 But neither was Cantwell's own alternative 'cap and dividend' legislation sufficiently strong on making cuts or committing to pay carbon debt for it to gain genuine traction amongst environmental advocates. Most scientists insist that at least an 80% drop in emissions will be necessary within four decades, with the major cuts before 2020. To achieve this, carbon markets won't work, as the leading US climate scientist, James Hansen, concluded in leading the intellectual opposition to US president Barack Obama's cap and trade scheme. Obama's legislation – the Waxman-Markey bill that passed the US House of Representatives in June 2009 (with similar Senate legislation on hold in 2010) – was so profoundly flawed that the more ambitious wing of environmental civil society argued it should be scrapped, not only because of its orientation to carbon markets, but simultaneously its destruction of Environmental Protection Agency's powers to regulate carbon pollution, plus the legislation's subsidization of fossil fuels and offsets. See the film 'Story of Cap and Trade' at <http://www.storyofstuff.org> and analyses by, e.g., the groups Center for Biological Diversity, Climate SOS and the Sustainable Energy and Economy Network, at http://www.biologicaldiversity.org/action/toolbox/ACESA/sign-on_letter.html, <http://www.climatesos.org> and <http://www.seen.org>.

- 6 See Bond, P. (2009a). According to Michael Dorsey, Professor of Political Ecology at the US's Dartmouth College, 'After more than a decade of failed politicking [on behalf of carbon trading], many NGO types... are only partially jumping off the sinking ship – so as to work for industries driving the problem. Unfortunately, many continue to influence NGO policy from their current positions, while failing to admit to or even understand obvious conflicts of interest'.
- 7 See: <http://www.globalpolicy.org/socecon/develop/devthry/well-being/2000/tandon.htm>
- 8 They include: (i) three dozen cases of African resources – worth billions of dollars – captured by firms for resale without adequate 'Access and Benefit Sharing' agreements between producers and the people who first used the natural products; (ii) diabetes drug produced by a Kenyan microbe and Libyan/Ethiopian treatment; (iii) antibiotics from Gambian termite hill and giant West African land snails; (iv) antifungal from Namibian giraffe and nematocidal fungi from Burkina Faso; (v) infection-fighting amoeba from Mauritius; (vi) Congo (Brazzaville) treatment for impotence; (vii) vaccines from Egyptian microbes; (viii) South African and Namibian indigenous appetite suppressant Hoodia; (ix) drug addiction treatments, multipurpose kombo butter from Central, W. Africa; (x) beauty, healing treatment from Okoumé resin in Central Africa; (xi) skin and hair care from the argan tree in Morocco, Egyptian 'Pharaoh's Wheat', bambara groundnut and 'resurrection plant'; (xii) endophytes and improved fescues from Algeria and Morocco; (xiii) groundnuts from Malawi, Senegal, Mozambique, Sudan and Nigeria; (xiv) Tanzanian impatiens; and (xv) molluscicides from the Horn of Africa.
- 9 The Bank's estimates are conservative for at least three reasons: a minimalist definition based upon international pricing in 2000 (not potential future values when scarcity becomes a more crucial factor, especially in the oil industry); the partial calculation of damages to the local environment, to workers' health/safety, and especially to women in communities around mines; and the Bank's use of average – not marginal – cost resource rents also probably leads to underestimations of the depletion costs.
- 10 Heads of State of Bolivia, Cuba, Dominica, Honduras, Nicaragua and Venezuela (2009), 'Declaration', Cumana.
- 11 As New York Times reporters remarked, 'Just a month after world leaders fashioned a tentative and nonbinding agreement at the climate change summit meeting in Copenhagen, the deal already appears at risk of coming undone' (see Broder and Rosenthal, 2010).
- 12 Trade Union Conference of the Americas (2009), 'Statement'.
- 13 PanAfrican Climate Justice Alliance (2009), 'Statement', Nairobi.
- 14 See: http://www.climate-justice-now.org/category/reports_and_publications/climate-debt/
- 15 Earthlife Africa (2009), 'Press Release: South Africa's Emissions Offer', Johannesburg, 10 December. Other agencies were more circumspect, maintaining good relations. For example, in early December a leading official of the World Wildlife Fund called Sonjica's Copenhagen strategy 'very progressive' and Greenpeace – so effective with direct action protests involving pranks and aesthetically gripping imagery (instead of grassroots organizing) – actually termed SA the 'star' of Copenhagen, prior to the Copenhagen Accord. Even a month after the Accord was signed, according to Themba Linden of Greenpeace Africa, 'The BASIC countries have to lead the world in light of no leadership from developed world.'
- 16 Lohmann, L. (2009), personal correspondence.

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Education, Convergence and Carbon Dioxide Growth per Capita

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SUMMARY

This paper examines the existence of convergence and the importance of education on carbon dioxide growth per capita, over the period 1970-2004 for 85 countries. We use panel data and apply GMM-System estimation. This rigorous approach takes into account the observed and unobserved heterogeneity of countries, and solves the endogeneity problems associated with some variables. Our results suggest a divergence in per capita carbon dioxide emissions around the world, and that education is not a factor in carbon dioxide emissions growth. Contrary to commonly held beliefs based on intuition, we provide evidence that, in developing countries, there is no convergence, and that education is not a factor in carbon dioxide growth. In developed countries, we find a convergence for per capita carbon dioxide emissions. Education was found to be a factor in pollution growth, although its effect is mitigated by the presence of political institutions.

INTRODUCTION

In recent years, the climate change debate has received renewed attention, because climate change associated environmental and socio-economic effects are more evident now than even before. In response, some agreements, such as the Kyoto Protocol, were signed between countries. These agreements establish flexible mechanisms and confirm the commitment of countries to stabilise or reduce greenhouse gas (GHG) emissions over the period 2008-2012. However, these commitments do not include developing countries, such as China or India. Despite this weakness, the Kyoto Protocol remains one of the best instruments of economic policy against pollution at an international level, and should be improved to integrate developing

countries. Among many options for including these countries, scientists promote the approach of Contraction and Convergence. This method involves a substantial reduction in carbon dioxide emissions (contraction) and gradual equalisation of per capita carbon dioxide emissions across countries (convergence). The aim of this approach is to allocate commitments to countries, to reduce air pollution from greenhouse gases. Countries can set sustainable emissions budgets, and share this budget on a per capita basis. This scenario is different from the current protocol, where emissions rights are proportional to historical levels. Emissions convergence can facilitate the participation of developing countries in pollution reduction, through adoption of an allocation scheme based on pollution per capita, without involving a substantial transfer of financial resources from developed countries to developing countries. Thus, the analysis of the convergence of air pollution is important in terms of international political policies.

This paper aims to determine the importance of education on air pollution growth, and the existence of convergence. First, based on the available empirical literature on air pollution convergence, we analysed the existence of convergence in per capita carbon dioxide emissions over the period 1970-2004 in 85 developing and developed countries. Other authors have analysed the convergence in per capita carbon dioxide emissions. For example, Strazicich and List (2003) found a beta convergence in carbon dioxide emissions in a sample of 21 industrialised countries over the period 1960-1997. They explain these results by the fact that these countries are on the downward sloping of environmental Kuznets curves, and that their incomes per capita are lower than incomes per capita at a steady state. Thus, pollution reduction would be lower at the transitional stage than after a steady state has been achieved. Nguyen (2005) examined convergence in carbon dioxide emissions for 100 countries from 1966 to 1996, and concluded that the environmental convergence hypothesis is a case of the glass either being half-full or half-empty. More precisely, countries with high initial CO₂ per capita emissions (relatively to sample averages) experienced a decrease in their relative emissions, whereas the relative emissions of low emissions countries remained unchanged during the study period. Stegman (2005) provides weak evidence for convergence in emissions per capita for a set of 97 countries from 1950-1999; and identified weak convergence in countries with very high rates of emissions per capita. Brock and Taylor (2010) examined empirical evidence for the existence of convergence in carbon dioxide emissions per capita for 22 OECD countries from 1960-1998. Based on their research, they developed the green Solow model, by introducing technical progress in the depollution activities sector in the traditional Solow model. This model generates a Kuznets environmental curve, with a balanced growth path of income

per capita. Empirically, they found an absence of absolute convergence in emissions per capita for 139 countries, and conditional convergence for OECD countries.

Second, we analyse the role of education in air pollution growth. Contrary to existing literature on economic growth, the environmental economics literature has not explicitly investigated the role of education in air pollution growth. Since the Rio Summit (1992), education has been considered to be an essential tool for both environmental protection and sustainable development. It is commonly held that educated people are more conscious of environmental problems, and therefore would make behavioural and lifestyle changes in favour of improving the environment. In addition, education is considered to be a driving force behind economic growth, and education fosters environmental protection.

Our results suggest a divergence in per capita carbon dioxide emissions worldwide. In developing countries, we did not find convergence in per capita carbon dioxide emissions and the engine of emissions growth reduction is technical progress. But we did find convergence in carbon dioxide emissions per capita in developed countries, where increased education was associated with increased air pollution growth. However, political institutions appear to be dampening this negative effect of education on air pollution growth.

The remainder of the paper is organised as follows. In Section 2, we address how education can influence environmental quality. In Section 3, an estimating equation is derived and results are shown, while in the last section, brief conclusions are presented along with policy recommendations.

LITERATURE REVIEW

Different approaches drawn from the literature on economic growth have been used to study convergence in air pollution. In this section, we present these methods and survey the empirical literature related to air pollution convergence.

CONVERGENCE IN AIR POLLUTION EMISSIONS

The concept of convergence in air pollution can be explored by employing several approaches adapted from the literature on economic growth. The first approach is sigma (σ) convergence. According to Sala-i-Martin (1990), sigma convergence is defined as the reduction in the spread or dispersion of air pollution emissions over time: usually measured using coefficient variation (cv) or standard deviation. The second approach is beta-convergence.

Beta convergence refers to the existence of a negative relationship between the growth rate of air pollution per capita and the initial level of pollution per capita. Beta convergence occurs when countries with high initial levels of per capita CO₂ emissions have lower emission growth rates than countries with lower initial per capita CO₂ emissions. In addition, there is convergence when cross country differences in air pollution are declining. The third approach, the dynamic distributional approach to convergence analysis proposed by Quah (1995a, 1995b, 1996, 1997, 2000), examines the distribution dynamics of air pollution emissions. According to Quah, estimation of beta convergence using the method of cross sectional regression analysis yields 'only average behavior', and does not produce relevant information on distribution dynamics, because it only captures representative economic dynamics. The dynamic distributional approach to convergence enables analysis and comparison of the distribution of a variable of interest at different dates. Finally, the last approach, stochastic convergence, is based on univariate time-series analysis, and was inspired by Carlino and Mills (1996). This method employs unit root specifications with a constant, and with or without a linear trend, for testing if shocks in air pollution per capita relative to the average for a country are temporary or tend to vanish over time. In other words, the time series approach to convergence analysis is based on the assumption that forecasts of variable differences converge to zero as the forecast horizon becomes arbitrarily long. If the differences between the countries' variable levels contain either a non-zero mean or a unit root, then the convergence condition is violated (Bernard and Durlauf, 1995, 1996).

EDUCATION AND ENVIRONMENTAL QUALITY

In this section, we examine and explore theoretical arguments concerning the relationship between education and environmental quality. In particular, two groups of articles are discussed.

The first group deals with the civic externalities of education. Nelson and Phelps (1966) consider that education enhances one's ability to receive, decode, and understand information; and that both information processing and interpretation impact learning and behavioural change. In recent years, education has been proposed as a vehicle for sustainable development, and by extension, the fight against pollution. Education is a permanent learning process that contributes to the training of citizens whose goal is the acquisition of knowledge, soft skills, know-how and good manners. It enables them to get involved in individual and collective actions, based on the principles of interdependence and solidarity. This will help coordinate person-society-environment relationships and support the emergence of

sustainable societies that are socio-politically and economically fair, here and elsewhere, now and for future generations.

According to Farzin and Bond (2006), the predicted positive effects of education on environmental quality can be channelled in three ways. First, educated people are expected to be more conscious of environmental problems, and therefore would display behaviours and lifestyles in favour of environmental improvement. In addition, educated people have better access to information about environmental damage, and may consequently change their behaviour. In support of this, Bimonte (2002) has shown that increased education is often accompanied by higher levels of environmental protection.

Second, educated people have a higher capacity or ability to use existing means and channels to express their environmental preferences. For example, they can organize into pressure groups or lobbies, to push for and achieve implementation of environmental public policies. Dasgupta and Wheeler (1997) analysed factors encouraging people to complain about environmental damage in China. They found that Chinese provinces with relatively low education levels displayed a lower marginal propensity to complain about environmental damage. Without education, people have little information about the harmful risks or the long-term effects of environmental damage, and are only aware of the obvious impact. Furthermore, less educated people have little confidence in their own capacity to influence authorities. In support of this, empirical studies from the World Bank (Wheeler et al., 1993) have shown that in the absence of effective government policies, communities with higher education levels take favourable actions to control or reduce pollution emissions.

Third, Farzin and Bond (2006) consider that educated people are 'more likely to generate an environmentally progressive civil service, and therefore have democratically-minded public policymakers and organizations that are more receptive to public demands for environmental quality'.

The second group focuses on the effect of education with respect to labour productivity and income. Specifically, according to the Environmental Kuznets Curve, environmental quality is initially reduced with rising incomes and development. At a given level, income rises are then associated with improvements in the environment. This effect is explained by fact that increased income levels generate the resources necessary for pollution abatement. In support of this, Jorgenson (2003) found that education has a positive effect on the ecological footprint. However, educated people have more income and purchasing power, and are encouraged to over-consume material goods. Indeed, they apparently fulfil a desire to live well by accumulating material goods, without caring about the consequences of this privilege: instead following the ideological model of 'consume more to

be happier' (Princen et al., 2001) conveyed by advertising and the media, leading to even greater consumption of material goods. Therefore, because overconsumption of goods is a factor in the over-exploitation of natural resources, educated people directly contribute to environmental degradation (pollution of air, soil, and water). These empirical results reveal a positive and significant effect of enrolment in school on the ecological footprint per capita.

Second, education facilitates the development and adoption of new technologies that are more productive in a closed economy (Bartel and Lichtenberg (1987)); and according to Wells (1972), educated people adopt innovation sooner than less educated people. In fact, marketing literature shows that early (consumers) purchasers of new products are more educated. Nelson and Phelps (1966, page 70) concluded that a 'better educated farmer is quicker to adopt profitable new processes and products since for him, the expected payoff from innovation is likely to be greater and the risk likely to be smaller; for he is better able to discriminate between promising and unpromising ideas, and hence less likely to make mistakes. The less educated farmer, for whom the information in technical journals means less, is prudent to delay the introduction of a new technique'.

Education also stimulates the creation of knowledge; resulting in innovation as a function of research and the dissemination of knowledge from research centres and institutions, and promoting new ideas. These institutions can train many engineers and scientists and develop a research sector that is favourable to pollution abatement. Formal Research and Development (R&D) spending is concentrated in OECD countries, and developing countries spend relatively less on basic science and innovations. Thus, developing countries rely even more on the international diffusion of technology. Interestingly, Eaton and Kortum (1999) concluded that international technology transfers are the major source of technical progress for both developed and developing countries; while Keller (2004) argues that technology comes more often from abroad (90% or more) than from inside the country. The important question remains: Is human capital also important for international technology adoption and diffusion? Empirical and theoretical articles suggest that this story has gained support. For example, Caselli and Coleman (2001) have shown that inward technology diffusion increases with a country's human capital. Other major determinants of international technology diffusion are research and development expenditures, trade through intermediate input imports, learning-by-exporting experience, foreign direct investment (FDI) and communication.

Finally, education can change the structure of exports, which can become relatively less polluting, increasing the capacity to implement environmental policies. If an economy grows initially with the accumulation of

polluting physical capital, and later with the accumulation of non-polluting human capital, then pollution can appear in the shape of a reversed U-curve.

EMPIRICAL ANALYSIS

(A) ECONOMETRIC SPECIFICATION

The econometric approach of our paper is to analyse the role of education on the growth of air pollution and the existence of convergence. For this purpose, we estimate the growth of carbon dioxide emissions per capita on the level of education and a set of control variables. We write the baseline model as follows:

$$\log\left(\frac{e_{i,t}}{e_{i,t-1}}\right) = \beta_1 \log(e_{i,t}) + \beta_2 \log(h_{i,t}) + \delta X_{i,t} + \alpha_i + \gamma_t + \varepsilon_{i,t} \quad (1)$$

with $e_{i,t}$ the average quantity of carbon dioxide per capita (in metric ton) in a country i in a year t , $h_{i,t}$ is education, $\varepsilon_{i,t}$ is the error term, γ_t is time effect, α_i is country specific effect and $x_{i,t}$ is control variables. These variables are investments, population growth rate, trade openness, political institutions and technical progress. The period ranges from 1970 to 2004 and data are compiled in five-year averages. Our sample is taken from 85 countries including 22 developed countries and 63 developing countries (See Appendices).

Firstly, we analyse the existence of air pollution convergence (β_1). If it is negative and significant we can conclude that countries with low carbon dioxide per capita emissions catch up countries with high carbon dioxide per capita emissions. In other words, convergence occurs when countries with high initial level of per capita CO2 emissions have lower emission growth rate than countries with low initial level of per capita CO2 emissions. Secondly, we evaluate the effect of education on air pollution growth $[(h)], (i,t)$.

(B) ESTIMATION METHOD

In order to estimate this model we use adequate econometric techniques. The panel data take into account transversal and temporal dimensions and the unobserved heterogeneity (for example influence of economic specificities and environmental policies, etc.). We can run estimations using OLS (Ordinary Least Square) or Fixed Effects (FE). These are inadequate because the former (OLS) does not take into account unobserved heterogeneity of countries and the latter (FE) is inadequate for dynamic models. We then take into account country and time fixed effects and use the System GMM

(Generalized Method of Moment). The first – differenced generalised method of moments estimators applied to panel data models addresses the problem of the potential endogeneity of some explanatory variables, measurement errors and omitted variables. The idea of the first – differenced GMM is ‘to take first differences to remove unobserved time invariant country specific effects, and then instrument the right-hand-side variables in the first-differenced equations using levels of the series lagged one period or more, under the assumption that the time varying disturbances in the original levels equations are not serially correlated’ (Bond, Hoeffler and Temple, 2001). The System GMM estimator combines the previous set of equations in first differences with suitable lagged levels as instruments, with an additional set of equations in levels with suitably lagged first differences as instruments. Blundell and Bond (1998) provide evidence with Monte Carlo simulations that System GMM performs better than first-differenced GMM, the latter being seriously biased in small samples when the instruments are weak. To test the validity of the lagged variables as instruments, we use the standard Hansen test of over-identifying restrictions, where the null hypothesis is that the instrumental variables are not correlated with the residual, and the serial correlation test, where the null hypothesis is that the errors exhibit no second-order serial correlation. In our regressions, none of the tests on the statistics allows us to reject the validity of the lagged variables as instruments as well as the lack of second order autocorrelation.

(C) DESCRIPTIVE ANALYSIS OF DATA

The data on carbon dioxide emissions per capita, the investment rate, the trade openness and the population growth rate are from the World Development Indicators (World Bank, 2005). The data on education and political institutions come respectively from Barro and Lee (2000) and Polity IV (2010).

The emissions of carbon dioxide per capita are measured in metric ton per capita and are estimated from the combustion of fossil energies and cement industries in the liquid, solid or gas form. Trade openness and investment respectively correspond to the share of the sum of exports and imports and investments in gross domestic product (GDP). As political institutions variable, we chose the index of polity (2), which is a score obtained by differentiating the index of democracy and the index of autocracy on a scale going from +10 (democracy) to -10 (autocracy). The indicator of democracy is characterised by the effective existence of institutional rules framing of the power and the presence of institutions enabling citizens to express their expectations and to choose political elites. Autocracy is characterised by the absence or the restriction of political competition, economic planning and control. The exercise of power is slightly constrained by institutions and

the leaders are only selected within a ‘political elite’. The data on education resulting from Barro and Lee (2000) correspond to the average schooling years in the total population.

Table 1 Descriptive statistics of emissions of dioxide carbon and education

	Mean	Std. Dev.	Min	Max
World				
Growth of emissions per capita	0.08	0.35	−4.44	2.76
Emissions per capita	4.56	7.91	0.001	78.61
Education	4.67	2.06	0.042	12.21
Developed countries				
Growth of emissions per capita	0.04	0.29	−1.03	2.76
Emissions per capita	12.26	12.11	1.72	78.61
Education	7.93	2.05	2.44	12.21
Developing countries				
Growth of emissions per capita	0.09	0.37	−4.44	2.59
Emissions per capita	2.17	3.55	0.001	29.10
Education	3.41	2.19	0.04	10.27
Notes: the total sample is composed of developed and developing countries over the period 1970–2004				

Source: Author

Table 1 presents descriptive statistics of education, carbon dioxide emissions level and growth rate. It shows a high growth rate of carbon dioxide emissions per capita in the world (8.23%). This can be explained by the pollution growth rate in developing countries (9.4%) indicating their importance in the pollution phenomenon, contrary to developed countries (4.3%). We also noticed that countries (Developed countries) with high carbon dioxide emissions are relatively more educated and have low carbon dioxide growth rate.

RESULTS

Table 2 presents results obtained using the System Generalized Method of Moments (System GMM). Column (1) shows the absence of conditional convergence in carbon dioxide emissions per capita in the world, because the coefficient is insignificant and equals (−0.003). Note that this coefficient is between the fixed effects (FE) estimator (−0.595) and OLS estimator (−0.0008), which (Table 7 in Appendices) are biased downward and upward in the dynamic panel (for a small time period) (Bond, 2002). This result is consistent with previous studies (Westerlund and Basher, 2008; Aldy,

Table 2 Effect of education on the growth of carbon dioxide per capita
(System GMM)

	All countries (1)	Developing countries (2)	Developed countries (3)	Developing countries (4)	Developed countries (5)
Log of initial carbon dioxide per capita	-0.003 (-0.18)	0.008 (0.05)	-0.305 (-2.17)**	-0.009 (-0.72)	-0.201 (-2.14)**
Log of investment	0.326 (2.50)**	0.315 (2.40)**	0.549 (3.19)**	0.401 (3.29)**	0.337 (2.85)**
Log of trade openness	0.086 (0.93)	0.203 (1.51)	0.027 (0.48)	0.151 (1.32)	0.017 (0.43)
Democratic institutions	0.036 (1.73)	0.043 (2.07)**	-0.049 (10.56)***	0.034 (1.75)**	-0.035 (1.36)
Growth of population	-0.034 (0.30)	-0.160 (1.43)	-0.104 (2.47)**	-0.15 (1.37)	-0.026 (1.84)**
Education	0.253 (0.83)	-0.219 (0.96)	0.445 (3.76)***	-0.047 (0.27)	0.545 (12.45)***
Education* democratic institutions				-0.008 (0.94)	-0.035 (2.91)***
Constant	-1.293 (1.84)*	-1.329 (1.90)*	-0.294 (1.91)*	-1.562 (2.32)*	-1.269 (2.51)**
Observations	229	182	47	182	47
Countries	85	63	22	63	22
AR (1) /AR(2) p value	0.82/0.21	0.57/0.75	0.52/0.40	0.70/0.36	0.07/0.18
Hansen Test p value	0.40	0.69	0.91	0.82	0.62
Number of instruments	17	17	14	17	14
Note: *significant at 10%; ** at 5%; *** at 1%. Temporal dummy variables are included. The period is 1970–2004 and data are compiled in five-year averages (70-74, 75-79, etc).					

2007), which found an absence of convergence in air pollution at the international level. Since countries develop pollution behaviours according to their economic development, we analysed the convergence in carbon dioxide per capita according to the level of development (i.e. developing countries and developed countries).

AIR POLLUTION CONVERGENCE ACCORDING TO ECONOMIC DEVELOPMENT

Columns 2 and 3 of Table 2 show results when the sample is restricted to developing countries and developed countries. We found conditional convergence in

carbon dioxide emissions per capita for developed countries, and divergence for developing countries. Our results are similar to Strazicich and List (2003) and Brock and Taylor (2010), who reported convergence in air pollution for OECD countries. Indeed these results confirm the hypothesis of convergence among the 23 member countries of the Organization for Economic Cooperation and Development (OECD) between 1960–1997 and 1960–1998.

Interestingly, we also observed that the effects of education and political institutions on pollution growth were significantly different, depending on the level of development. In fact, education favours pollution growth in developed countries, in contrast with developing countries where education was not associated with decreased pollution growth. Political institutions contribute to pollution growth in developing countries and attenuate pollution growth in developed countries.

The role of institutions and human capital as fundamental sources of differences in economic development, as highlighted by the economic literature, suggests the possibility that the effect of education on the environment could differ according to the quality of institutions in a given country.

INTERACTION BETWEEN EDUCATION AND INSTITUTIONS

When considered to be a public good, improvements in the quality of the environment are not directly determined by individual preferences, but rather indirectly through political institutions. In other words, the interaction between education and political institutions could affect environmental protection. Mahon (2002) hypothesised that the effect of education on the quality of the environment could be significantly greater in the presence of stable political institutions that are considered to be a channel of expression for the people. Inclusion of an interactive variable between education and institutions in our equation suggests that the effect of education on pollution growth is conditional on political institutions.

Columns (4) and (5) confirm that the growth rate of carbon dioxide per capita positively and significantly depends on the investment rate. This variable is an important determinant of air pollution in developing countries. In these countries, people are not very concerned about environment problems; and are more worried about development problems (e.g. low and unstable growth, unemployment). These investments can also reduce poverty because they are a driving force of economic growth. Foreign and domestic investments allow countries to access international markets, trade, and develop new technologies and competences. However, these opportunities differ with the level of development in the country.

In some countries, investments are directed toward buildings, services and manufacturing sectors. In other countries, they are directed toward the

natural resource sector: in particular oil firms and wood companies, which are big energy consumers, and thus pollutants. For example, in Africa, 65 per cent of direct foreign investments go to the natural resources sector. The expected effects are a rise in employment, taxes, state revenues, and a reduction of poverty. As such, these countries can also be less sensitive to environmental problems. In the same way, infrastructure weaknesses, particularly roads, strongly increases the use of energy and the consumption of polluting resources.

Political institutions have a significant and opposite effect, based on the level of development. In developing countries, the positive effect can be explained by free rider behaviour (*Carlsson and Lundström, 2003*), where political leaders consider pollution to be a public good and have no willingness to fight it. In contrast, in developed countries, political institutions reduce carbon dioxide per capita growth; an effect which is more significant with education. Columns (3) and (5) demonstrate that the effect of the quality of institutions on pollution growth is conditioned by the level of education.

Education also seems to be a factor in air pollution in developed countries, although its effect is slightly mitigated by the presence of political institutions. In the absence of political institutions, education increases pollution. Our results are similar to Jorgenson's (2003). As mentioned in the literature review, a possible explanation is that educated people have higher incomes and are encouraged to over-consume. They also fulfil their desire to live well by accumulating material goods without caring about the consequences of this happiness: following the ideological model of 'consume more to be happier' (Princen et al., 2001). However, political institutions mitigate this negative effect of education. In addition, although they pollute, educated people are also more conscious of environmental problems. Thus, their increased education level will increase their preferences for higher levels of environmental protection, which they will reflect through political institutions.

In developing countries, education and its interactive variable have no effect on the growth of carbon dioxide emissions per capita. Low education levels and the relative weakness of political institutions might explain the absence of an effect of education in developing countries. The combination of these factors strongly reduces the ability of people to express their preferences for a better environment. Therefore, the average effect of education on emissions growth is negligible. Furthermore, less educated people (relative to those in developed countries) are also poor and consume less material goods, which is a factor in environmental degradation.

While technical progress has no impact on pollution growth in developed countries, it is the key driving force behind depollution in developing

countries. These results are not surprising. In developed countries, high education levels are also factors in the advancement of knowledge and technical progress; in contrast, developing countries produce little technical progress and require technology transfers. Because the level of technical progress is relatively low and their technological needs are so enormous, an increase in technical progress (e.g. new technology transfers) has only a high marginal effect on pollution reduction. In other words, technical progress is more effective in countries that are weakly endowed with such progress.

ROBUSTNESS CHECKS

To analyse the strength of our results, we considered eight other educational measures. These are: the average of years of schooling in general for individuals over 25 years old; the average of years of higher level schooling for individuals over 15 years old; the average of years of higher level schooling for individuals over 25 years old; the average of years of secondary level for individuals over 15 years old; the average of years of secondary level for individuals over 25 years old; the percentage of the population who completed some form of higher education; the percentage of the population who completed secondary school; and the percentage of the population who completed primary school. As suggested by Tables 3 and 4, our results remain stable in spite of the use of eight alternative variables. Thus, the average primary, secondary and higher school years in the population have similar effects on the growth of carbon dioxide emissions per capita, and these effects are different according to the country's level of development.

Second, we checked if the effect of education on the growth of emissions per capita was simply due to omission of the income variable (GDP per capita). From the point that education contributes to a rise in income and economic growth, education increases the use of environmental resources. It is thus a source of air pollution growth through increased income per capita. Our results may also be simply explained by omission of income (GDP/capita). Thus, to control for the relevance/accuracy of our results, we included income per capita. Columns 1 and 4 of Table 5 show that income per capita does not have a significant effect on the growth of emissions per capita. Results are stable, coherent and valid.

In recent years, the debate on climate change has been renewed because environmental and socio-economic effects are now more evident. In response, several international agreements were signed between countries. To take into account the effect of international agreements, we included The United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol.

Table 3 Effect of alternative education variables on the growth of carbon dioxide per capita (GMM-System) in developed countries

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Log of initial carbon dioxide per capita	-0.16 (-2.05)**	-0.15 (-2.98)***	-0.14 (-2.89)***	-0.24 (-2.64)***	-0.16 (-2.02)**	-0.13 (-2.71)***	-0.14 (-2.28)**	-0.30 (-2.30)**
Educ1	0.539 (12.52)***							
PolityEduc1	-0.040 (3.89)***							
Educ2		0.447 (13.27)***						
PolityEduc2		-0.038 (6.68)***						
Educ3			0.439 (13.62)***					
PolityEduc3			-0.039 (7.22)***					
Educ4				0.588 (10.91)***				
PolityEduc4				-0.039 (4.37)***				
Educ5					0.487 (10.46)***			
PolityEduc5					-0.044 (10.02)***			
Educ6						0.442 (11.70)***		
PolityEduc6						-0.038 (8.53)***		
Educ7							0.522 (9.76)***	
PolityEduc7							-0.048 (11.79)***	
Educ8								0.551 (10.49)***
PolityEduc8								-0.043 (8.72)***
Number of countries	22	22	22	22	22	22	22	22

Notes: *significant at 10%; ** at 5%; *** at 1%. The period is 1970 to 2004 and data are compiled in five-year averages. Variables Educ1,..., Educ8 correspond respectively to the logarithm of: the average schooling years in general for individuals over 25 years old, 15 years old; the average schooling years at a higher level for individuals over 25 years old; the average schooling years at a secondary level for individuals over 15 years old; the average schooling years at a secondary level for individuals over 25 years old; the percentage of the population having completed higher education; the percentage of the population having completed secondary school; and the percentage of the population having completed primary school.

Table 4 Effect of alternative education variables on the growth of carbon dioxide per capita (GMM-System) in developing countries

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Log of initial carbon dioxide per capita	-0.11 (-0.28)	0.05 (-0.10)	-0.16 (-0.42)	-0.47 (0.69)	-1.15 (-0.67)	-0.03 (-0.08)	0.42 (0.52)	-0.41 (0.74)
Educ1	-0.204 (0.37)							
PolityEduc1	-0.001 (0.09)							
Educ2		-0.114 (0.30)						
PolityEduc2		-0.002 (0.34)						
Educ3			0.074 (0.31)					
PolityEduc3			-0.001 (0.28)					
Educ4				-0.531 (0.89)				
PolityEduc4				-0.013 (0.85)				
Educ5					-0.429 (0.62)			
PolityEduc5					0.001 (0.05)			
Educ6						-0.047 (0.15)		
PolityEduc6						-0.002 (0.35)		
Educ7							1.102 (0.65)	
PolityEduc7							0.016 (0.54)	
Educ8								-0.619 (0.83)
PolityEduc8								-0.009 (0.69)
Number of countries	65	63	65	63	65	63	63	63

Notes: * significant at 10%, ** significant at 5%, *** significant at 1%. The period is 1970-2004. Variables Educ1,... Educ8 correspond respectively to the logarithm of: the average schooling years in general for individuals over (25 years old;15 years old); the average schooling years at a higher level for individuals over 25 years old; the average schooling years at a secondary level for individuals over 15 years old; the average schooling years at a secondary level for individuals over 25 years old; the percentage of the population having completed higher education; the percentage of the population having completed secondary school; and the percentage of the population having completed primary school

Table 5 Effect of education on the growth of carbon dioxide per capita, including international agreements and income

Growth of carbon dioxide per capita (GMM-system)	(1)	Developed countries		(4)	Developing countries		(7)
		(2)	(3)		(5)	(6)	
Log of initial carbon dioxide per capita	-0.19 (-2.14)**	0.19 (3.16)***	0.19 (2.92)***	-0.084 (-0.61)	0.11 (0.99)	0.19 (1.30)	0.15 (0.52)
Log of investment	0.340 (2.80)**	0.330 (1.39)***	0.328 (1.37)***	0.402 (3.30)***	0.388 (3.21)***	0.489 (3.52)***	0.39 (2.69)***
Log of trade openness	0.026 (0.51)	0.025 (0.46)	0.024 (0.43)	0.147 (1.30)	0.068 (0.50)	0.044 (0.36)	0.013 (0.11)
Technical progress	0.031 (1.04)	0.046 (0.43)	0.047 (0.70)	-0.178 (2.16)**	-0.104 (2.01)**	-0.091 (1.71)*	-0.04 (1.85)*
Political institutions	0.035 (1.45)	0.943 (0.22)	0.717 (0.12)	0.034 (1.76)*	0.036 (1.89)*	0.033 (2.24)**	0.043 (2.24)**
Population rate	-0.029 (1.69)	-0.093 (1.69)	-0.096 (1.66)	-0.140 (1.27)	-0.100 (0.81)	-0.075 (0.69)	0.004 (0.13)
Education	0.542 (12.63)***	18.015 (2.32)**	13.918 (2.25)**	0.005 (0.02)	0.084 (0.56)	0.212 (1.07)	-0.008 (0.04)
Education* Political Institutions	-0.036 (3.14)***	-1.787 (2.32)**	-1.377 (2.24)**	-0.009 (0.95)	-0.010 (0.90)	-0.004 (0.49)	-0.02 (1.04)
Log of income per capita	0.006 (0.42)			0.004 (0.33)			
UNFCCC		0.090 (1.54)			-0.018 (0.06)		
Kyoto			0.081 (1.14)			-0.134 (1.15)	
CDM							0.21 (1.19)
Constant	-1.407 (2.55)**	-10.193 (2.25)**	-7.913 (2.16)**	-1.61 (2.46)**	-0.877 (1.84)*	-1.232 (2.27)**	1.48 (2.17)*
Observations	47	47	47	161	170	170	170
Number of countries	22	22	22	63	63	63	63
AR (1)	0.22	0.071	0.06	0.51	0.32	0.35	0.52
AR (2)	0.72	0.24	0.17	0.81	0.45	0.47	0.40
Hansen Test	0.83	0.75	0.69	0.72	0.72	0.48	0.90
Number Instruments	14	15	15	17	27	27	27
Notes: * significant at 10%, ** significant at 5%, *** significant at 1%. The period is 1970 to 2004 and data are compiled in five-year averages (70-74, 75-79, etc). Temporal dummies are taken into account.							

The UNFCCC is an international environmental treaty produced at the Earth Summit in Rio de Janeiro (1992). The objective of the Treaty was to encourage stabilisation of the concentration of greenhouse gases at a level that

would prevent dangerous anthropogenic interference with the climate system. The Kyoto protocol establishes flexible mechanisms and commitments on the part of countries to stabilise or reduce the emissions of greenhouse gases (GHGs) by 5.3 per cent over the period 2008–2012. Thus, we were very interested in testing the impact of the Kyoto Protocol and UNFCCC on the growth of carbon dioxide per capita. In Table 5 (columns 2, 3, 5, 6 and 7), we include ‘Kyoto’ and ‘UNFCCC’ variables. The dummy takes a value of one if a country has ratified the Kyoto Protocol or the UNFCCC treaty, and faces emissions reduction obligations; otherwise it takes a value of zero. Our results show that the Kyoto Protocol and the UNFCCC have no direct impact on the growth of carbon dioxide per capita. Two arguments can explain these results. First, it is still very early to verify the effects of the Kyoto protocol commitments on air pollution growth, because our analysis covers the period 1970–2004, and many countries only ratified it in 2002. Second, countries are not prompted to respect their international agreements.

CONCLUSION

This study examined convergence in air pollution and the effect of education on the growth of air pollution over the period 1970–2004 in 85 countries. Our results show a divergence in carbon dioxide per capita at a global level during the period 1970–2004. For developing countries, there is a divergence in carbon dioxide per capita.

Our results also suggest that education has no impact on the growth of air pollution in the total sample (85 countries). However, this effect is heterogeneous between the countries according to their level of development. Indeed, while its effect remains insignificant in the developing countries sub-sample, education does matter for pollution growth in the developed countries. More interestingly, when controlled for the quality of democratic institutions, the positive effect of education on air pollution growth is mitigated in developed countries, while it is insignificant in developing countries.

Technical progress contributes to a reduction in air pollution growth. Investment, which is the driving force behind economic growth, is an important source of pollution in both developing and developed countries.

Our results are important for economic policy development. Initially, they highlight the importance of education in environmental protection. The current accumulation of knowledge is a factor in both economic growth and pollution growth. We are not recommending questioning education policies, whose intrinsic values are obvious. On the contrary, there is a need for introducing a changed perception of the role of education, in favour of

the environment. This should be very urgently implemented in developing countries, because the realisation of the Millennium Development Goals (MDG) regarding education will be followed by environmental pollution. Then, there is the free rider phenomenon practised by some countries in the fight against climate change. In addition, because investments are a key factor in economic growth and a determinant of pollution, reduction of these effects should be necessarily followed by the establishment of ecologically appropriate investments. Finally, the divergence of air pollution at an international and developing countries levels requires transformation of the Kyoto protocol, which should include agreements for technology transfers and the promotion of ecological development.

This paper opens several avenues for future research. Indeed, our results highlight the convergence and divergence in air pollution for developed and developing countries, respectively. It will therefore be interesting to analyse deeper determinants of air pollution convergence with respect to economic development.

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APPENDICES

LIST OF COUNTRIES INCLUDED IN THE SAMPLE

Australia, Austria, Belgium, Canada Denmark, France, Finland, Germany, Greece, Holland, Israel, Italy, Japan, Luxemburg, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, The USA. Algeria, South Africa, Burundi, Benin, Bangladesh, Bahrain, Bolivia, Brazil, Botswana, Central Africa, Chile, China, Cameroun, Congo, Colombia, Costa Rica, Dominican Republic, Ecuador, Egypt, Fiji, Ghana, Guatemala, Honduras, Haiti, Hungary , Indonesia, India, Iran, Jamaica, Jordan, Kenya, Mexico, Mali, Mauritania, Malawi, Malaysia, Niger, Nicaragua, Nepal, Pakistan, Peru, Philippines, New Guinea, Guinea, Poland , Paraguay, Rwanda, Senegal, Sri Lanka, Sierra Leone, El Salvador, Syria,Togo, Thailand, Trinidad and Tobago, Tunisia, Turkey , Uganda,Uruguay, Zambia.

Table 6 Definition and source of variables

Variables	Definitions	Data Source
Carbon dioxide per capita	Carbon dioxide per capita (metric ton per capita)	World Development Indicators (2005)
Emissions per capita initial	Carbon dioxide per capita at the beginning of each period	
Investment rate	Investment/GDP	
Trade openness rate	(Exports+Imports) / GDP	
Population growth rate	Population growth rate	
Political institutions	Combined score of democracy and autocracy on a scale going from –10 to 10. (–10) large represents a big autocracy and 10, large democracy	Polity IV
Education	Average schooling years in the total population	Barro and Lee (2000)

Table 7 Effect of education on the growth of carbon dioxide pe capita with Fixed effects (FE) and (Ordinary Least Square)

	All countries		Developed countries			
	F E	OLS	FE	OLS	FE	OLS
Log of initial carbon dioxide capita	-0.595*** (-15.26)	-0.0008*** (-4.810)	-0.346*** (-4.993)	-0.158*** (-4.507)	-0.237** (-2.696)	-0.175*** (-4.591)
Log of investment	0.244*** (3.302)	0.408*** (7.197)	0.129 (1.261)	0.322*** (3.686)	0.0272 (0.241)	0.249*** (2.983)
Log of trade	0.216*** (3.233)	-0.0104 (-0.399)	-0.228** (-2.059)	-0.0225 (-0.940)	-0.188* (-1.725)	-0.0409 (-1.609)
Technical progress	-0.00697 (-0.455)	0.00317 (0.211)	0.00366 (0.187)	0.0100 (0.676)	-0.00244 (-0.127)	0.00748 (0.499)
Political institutions	0.00177 (1.080)	0.00157 (1.017)	-0.00799 (-1.193)	-0.000782 (-0.146)	0.0141 (1.068)	0.0224 (1.265)
Education	0.0462 (1.098)	0.0572*** (3.212)	0.122** (2.164)	0.0160 (0.695)	0.277*** (2.843)	0.133* (1.836)
Political institutions *education					-0.0176* (-1.918)	-0.0117 (-1.621)
Constant	-1.507*** (-5.741)	-0.955*** (-4.471)	1.148* (1.886)	-0.382 (-1.229)	0.951 (1.592)	-0.286 (-0.994)
Observations	292	292	73	73	73	73
R-squared	0.642	0.331	0.852	0.807	0.865	0.821
Countries	88		23		23	
Note: *significant at 10%; ** at 5%; *** at 1%. Temporal dummy variables are included. The period is 1970-2004 and data are compiled in five-year averages (70-74, 75-79, etc.)						

Table 8 Descriptive statistic

Variables	Mean	Std. Dev.	Min	Max
Log of initial per capita dioxide carbon	4.56	0.35	0.0015	78.61
Growth rate of dioxide carbon per capita	0.08	7.91	-4.44	2.76
Investment rate	21.42	7.39	2.53	86.79
Trade openness rate	71.14	41.51	5.71	297.33
Political institutions	0.49	7.47	-10.00	+10.00
Population growth rate	1.97	1.61	-20.36	16.17
Education	4.67	2.95	0.042	12.21

Source WDI (2005), Polity IV, Barro and Lee (2000)

Green Markets of the Future

An Economic Opportunity also for Newly Industrializing Countries and South Africa?

Rainer Walz

SUMMARY

Competences for green technologies in Newly Industrializing Countries (NICs) are becoming increasingly urgent from a global perspective. These technologies open up the opportunity for reducing emissions and modernising the infrastructure, and the prospect of exporting them can add an incentive for NICs to push in that direction. The article analyses whether or not NICs have already obtained some of the competences necessary to exploit these opportunities. It uses innovation indicators for publications, patents, and trade. The results indicate that some of the NICs, among them South Africa, have already started to develop the necessary build-up of competences, but others are unlikely to benefit from the economic opportunities.

The wide range of results for different green technologies within South Africa underlines the need to perform such analysis on a disaggregated level. Furthermore, the green technology development is embedded in the overall performance of the South African innovation system, and depends on its improvements. A widening of the policy focus from a narrow definition of R&D institutions towards both the demand side and environmental regulation is necessary. Strengthening environmental regulation in South Africa must not be seen as a trade-off between environmental protection and economic development, but as an instrument of demand side driven innovation policy in one of the fastest growing technology sectors.

INTRODUCTION

Competences for green technologies in Newly Industrializing Countries (NICs) are becoming increasingly urgent from a global perspective, that is in the fields of climate mitigation and adaptation, sustainable

transportation, and the water sector (e.g. IPCC, 2007; United Nations 2009; Sachs and McArthur, 2005; Landergraber and Muellegger, 2005). In this article, the opportunities of NICs are analysed for six fields of green technologies: (1) energy efficiency, both in buildings and in industry; (2) environmental friendly energy supply technologies, including renewable energy, cogeneration and CO₂ neutral fossil power stations; (3) material efficiency, including renewable resources and ecodesign of products; (4) transport technologies; (5) water technologies; and (6) waste management technologies. These technologies open up the opportunity for reducing emissions and modernising the energy, water and transport infrastructure in NICs. The prospect of exporting environmentally sound technologies can add an incentive for NICs to move towards sustainability technologies. The goal is to measure whether or not NICs have already obtained some of the competences necessary to exploit these opportunities.

This paper starts with conceptual issues: The development of green technology markets in the future is presented. Building technological competences as prerequisite in the Newly Industrializing Countries (NICs) for successful absorption and export success in these technological fields is discussed. Furthermore, the empirical research concept is introduced, which consists of a top-down innovation indicator approach for measuring the technological capabilities.

In the second part, selected NICs are analysed. The technological capabilities in sustainability technologies are analysed with publication, patent and trade indicators. In the third part, disaggregated results are presented for South Africa. Finally, based on these results, first conclusions for the role of sustainability innovations for the economic development process in NICs and South Africa are drawn.

CONCEPTUAL ISSUES

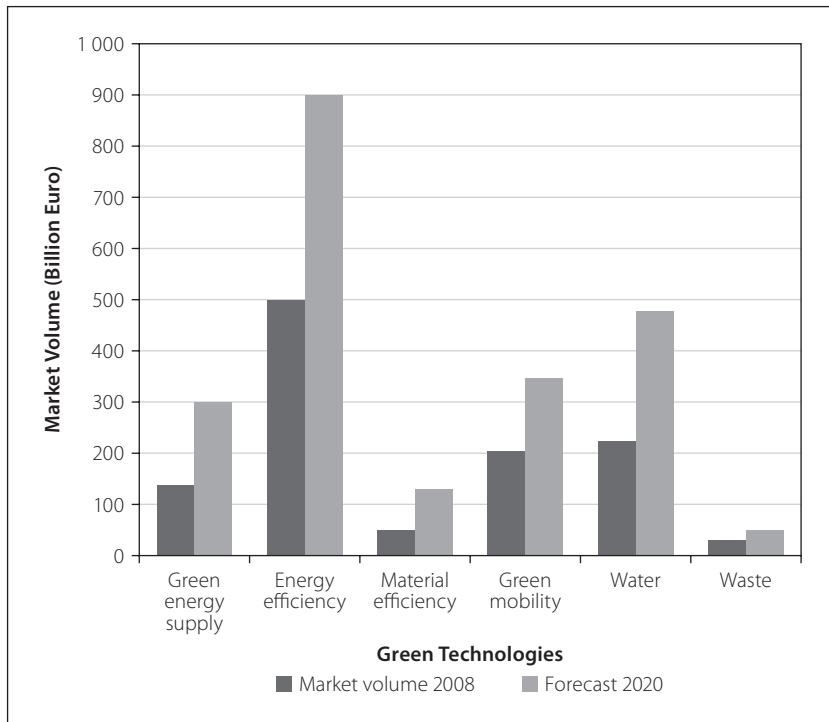
Green technology markets of the future: There is general consensus that environmental sustainability requires innovations and improved green technologies. Even though technology alone is not enough for reaching the Millennium Development Goals, it is still important to increase innovation, access and diffusion of technologies (Sachs and McArthur, 2005; Clemens et al., 2007; UN, 2009). This also applies to the environmental sustainability related goals. The discussion of the Environmental Kuznets Curve Hypothesis reveals the need for green technologies in combination with active policies and regulations and an appropriate institutional setting (Ekins, 1997; Dinda, 2004; Dutt, 2009). This also holds for the application of this concept to developing countries and the associated concepts of ‘tunneling through the EKC’ or

'leapfrogging' (Munashinghe, 1999; Perkins, 2003; Gallagher, 2006). Market forecast show that the technology fields associated with green energy supply, energy efficiency, water technologies, sustainable mobility and material efficiency will show above average growth rates in the next 10 years (Roland Berger, 2007; ECORYS et al., 2009). Clearly there is a huge market potential to be realised by the countries which specialise on supplying the world markets with these technologies (see Figure 1).

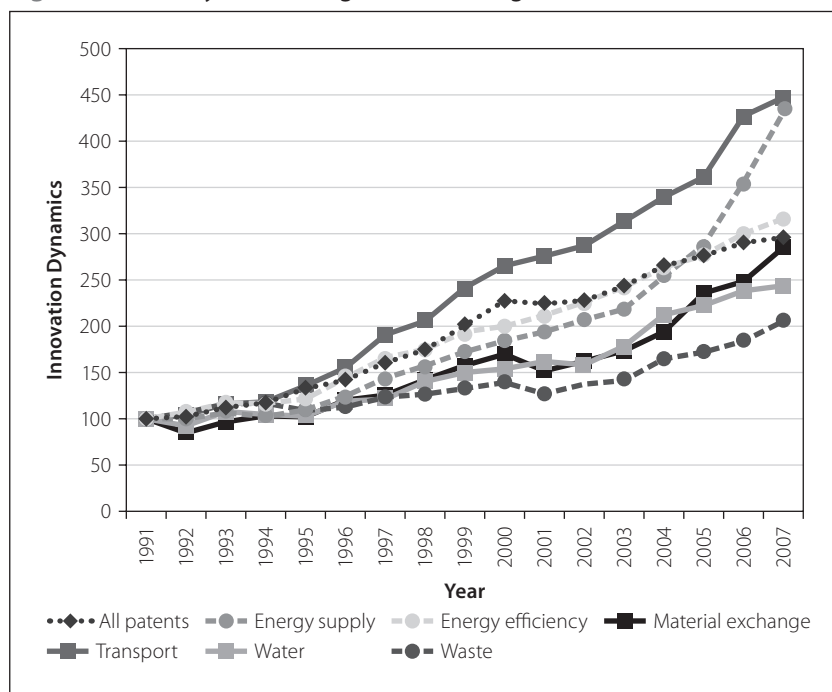
Green technologies are, in general, medium-high technologies (Grupp, 1999). The comparison of patent development with all patents indicates a rather high innovation dynamics (Walz et al., 2008; Walz and Schleich, 2009). Figure 2 shows that especially green transport technologies, and in the last years green energy supply, have shown a very strong dynamics. A high innovation dynamics indicates that trade and market shares are not only decided on by cost comparisons, but also by quality differences and the capability to bring new solutions to the market. Thus, it can be concluded that, by and large, market success in green technologies requires substantial technological capabilities.

Green technologies and NICs: Green technologies have been developed and supplied mainly by the OECD-countries in the past (Walz et al., 2008). However, the need for green technologies also holds for Newly

Figure 1 Market volume for green technologies (in billion Euro)



Source Data from DIW/ISI/Berger (2007); Roland Berger (2007); ECORYS et al. (2009).

Figure 2 Patent dynamics for green technologies (1991 = 100)

Source: Calculations from Fraunhofer ISI

Industrialising Countries (NICs). Two additional questions have to be addressed in this context:

- First, are the NICs – given their stage of development – able to absorb the green technologies, especially because they require substantial technological capabilities?
- Second, is the interest of the NICs strong enough to push in the direction of integrating green technologies into their economic development programme?

The first question addresses issues of the debate on absorptive capacities and technological gaps, which can be traced far back. This approach gained prominence among the scholars developing an evolutionary theory of trade (Soete, 1985; Perez and Soete, 1988; Dosi et al., 1990). Technological cooperation focuses on the knowledge base required by the technologies and on enabling competences in the countries. Since the end of the 1980s, the concepts of social or absorptive capacity (Abramovitz 1986; Cohen and Levinthal, 1990) and technological capabilities (Lall, 1992; Bell and Pavitt, 1993) are widely known. The results of the research on technological development in NICs and the factors which influence the build-up of their technological capabilities (e.g. Fagerberg and Godinho, 2005; Nelson, 2007;

Malerba and Nelson, 2008; Lall, 1998; Lee and Lim, 2001; Lee, 2005; Lee and Lim, 2005; Rasiah, 2008; Wamae 2009) have underlined the importance of absorptive capacity and competence building. Clearly, this underlines the need to build functioning innovation systems in countries of the South (Muchie et al., 2003; Baskaran and Muchie, 2007; Cassiolato and Vitorino 2009; Malerba and Mani, 2009).

This challenge has to take into account the changing conditions for learning and knowledge acquisition. One aspect to consider is the tendency that the building up of technological and production capabilities are becoming increasingly separated (Bell and Pavitt, 1993). Another aspect relates to the effect of globalization on the mechanisms for knowledge dissemination. Archibugi and Pietrobelli (2003) stress the point that importing technology has per se little impact on learning, and call for policies to upgrade cooperation strategies towards technological partnering. Nelson (2007) highlights the changing legal environment and the fact that the scientific and technical communities have been moving much closer together. All these factors lead to the conclusion that indigenous competences in green technology related science and technology fields are increasingly a prerequisite for the successful absorption of green technologies in NICs.

The debate on environmental incentives is often based on the pollution haven hypothesis and the environmental dumping mechanism. It can be argued that there might be a disincentive for strong environmental policies in the NICs in order to attract pollution intensive industries (Copeland and Taylor, 2004). However, there are also different incentives for NICs to push for sustainability technologies: Firstly, environmental problems and related health issues are becoming major issues within NICs, and many of the green technologies would help to improve this domestic environmental pressure. Secondly, many of the green technologies improve the infrastructure, e.g. in the energy, water or transportation sector, or address the growing demand for raw materials. Thus, they are also part of an economic modernisation strategy. Thirdly, another incentive is that NICs engage in the development and production of these technologies and compete with the countries of the North for supplying the world market.

The economic rationale for pushing for green innovations in order to realise export potential is linked to the concepts of first mover advantages and lead markets. A first-mover advantage requires that competition is driven not so much by cost differentials and the resulting attractiveness of international production location alone, but also by quality aspects. Empirical results indicate that under these conditions, unit labor costs play a lower role in determining exports (Amable and Verspagen, 1995; Wakelin, 1998). Above all, for technology-intensive goods, which include many environmental innovations, high market shares depend on the innovation

ability of a national economy and its early market presence. Thus, the argument can be made that if countries push for green technologies, they tend to specialise early in the supply of the necessary technologies. If there is a subsequent expansion of the international demand for these technologies, these countries are then in a position to dominate international competition due to their early specialization in this field.

The following factors have to be taken into account when assessing the potential of countries to become a lead market in a specific technology (Walz, 2006; Walz and Schleich, 2009):

- Lead market capability: it is not possible to reach a lead-market position for every good or technology. One prerequisite is that competition is driven not by cost differentials alone, but also by quality aspects. This prerequisite is fulfilled especially for knowledge-intensive goods. Other important factors are intensive user-producer relationships and a high level of implicit knowledge (Archibugi and Michie, 1998; Archibugi and Pietrobelli, 2003; Dosi et al., 1990; Fagerberg, 1995).
- The demand side is an important part of the analysis of von Hippel (1986), Porter and van der Linde (1995) or Dosi et al., (1990). Beise (2004) classifies the demand factors in 5 categories, distinguishing demand and price advantage, market structure, and transfer and export advantage.
- A lead market situation must also be supported by innovation-friendly regulation (Beise and Rennings, 2005; Walz, 2006 and 2007). However, there is a lot of additional research necessary to develop a clear methodology on how to operationalise the innovation friendliness of regulation.
- It is widely held that innovation and economic success also depend on how a specific technology is embedded into other relevant industry cluster. Learning effects, expectations of the users of the technology and knowledge spillovers are more easily realised if the flow of this (tacit) knowledge is facilitated by proximity and a common knowledge of language and institutions (Archibugi and Pietrobelli, 2003; Dosi et al., 1990).
- It has become increasingly accepted that international trade performance depends on technological capabilities (for an overview see Dosi et al., 1990; Fagerberg, 1994). Despite all the problems and caveats associated with measuring technological capabilities, indicators on R&D expenditures and patent indicators such as share of patents or the relative patent advantage are among the most widely used indicators. The empirical importance of these indicators for trade

patterns is also supported by recent empirical research (e.g. Sanyal, 2004; Andersson and Ejermo, 2008; and Madsen, 2008).

Altogether, it is more and more acknowledged that the absorption of developed technologies and the development of abilities to further advance these technologies and their international marketing are closely interwoven (Nelson, 2007). For both strategies – absorption of knowledge from traditional industrialized countries and establishing export oriented market success – it is necessary to develop substantial capabilities for sustainability innovations within the NICs. Furthermore, the system of innovation approach implies to include more than only the R&D institutions in the process. Especially for green technologies, government policies and demand driven innovation policies are a key for future success (Walz, 2007; Bergek et al., 2008).

Research concept: This paper concentrates on an indicator framework to develop a top down macro overview on the technological capabilities in green technologies in NICs. The following technological fields were included under the heading of green technologies: (1) energy efficiency, both in buildings and in industry; (2) environmental friendly energy supply technologies, including renewable energy, cogeneration and CO₂ neutral fossil fuels, but excluding nuclear energy; (3) material efficiency, including renewable resources and ecodesign of products; (4) transport technologies; (5) water technologies; and (6) waste management technologies. In addition to an analysis for the aggregate of sustainability innovations, a more disaggregated analysis for South Africa is performed.

Measuring technological capabilities can draw on the experience with innovation indicators made over the last two decades (see Grupp, 1999; Smith, 2005; Freeman and Soete, 2009). In the remaining part of this section, empirical results for the following aspects are presented:

- Publication data is taken from the Science Citation Index; SCI provides also for bundling journals into thematic clusters, such as environmental engineering; this classification was used in the analysis for this paper.
- Patents are among the most used indicators in innovation research. They belong to the intermediate output indicators of knowledge build up, and are directly related to technological capabilities. The analysis draws on patent applications at the World Intellectual Property Organization and thus transnational patents (for the concept see Walz et al., 2008; Frietsch and Schmoch, 2010). In this way, a method of mapping international patents is employed which does not target individual markets but is much more transnational in character. The patents identified in

this way reveal those segments in which patent applicants are already taking a broader international perspective. The latest year available is 2007, the years 2003–2007 were chosen as the period of study so that a statistically more reliable population is achieved in which chance fluctuations in individual years are evened out.

- International trade figures indicate the degree to which a country is able to compete internationally. The competitiveness with regard to technology intensive goods is influenced by the technological capabilities of the countries. Sustainability innovations mostly fall into the category of sectors which are classified as medium-high-technologies industries. Thus, trade figures for these technologies also indicate the degree of technological capabilities. The database UN-COMTRADE is referred to for trade figures. The classification of the technologies is using the Harmonized System (HS), 2002. This foreign trade classification allows more disaggregation and therefore a better targeting of the sustainability technologies compared to the older classifications common in international comparisons (Standard International Trade Classification SITC). The latest year available for the analysis was 2007.

For patents and world trade, the share of the NICs at the world total was calculated (patent share, world export share). Furthermore, specialisation indicators (relative patent advantage (RPA), relative export activity (RXA), relative literature advantage (RLA) and revealed comparative advantage (RCA) were calculated, in order to analyse whether or not the NICs specialise on the sustainability technologies:

For every country i and every technology field j the Relative Patent Activity (RPA) is calculated according to:

$$RPA_{ij} = 100 * \tanh \ln \left[\frac{(p_{ij} / p_j)}{(\sum_i p_{ij} / \sum_{ij} p_{ij})} \right]$$

The RXA and RLA are calculated in a similar way as the RPA, by substituting patents (p) by exports (x) and literature publications (l) respectively.

In addition to exports, which are the basis of the RXA, the RCA was also calculated in order to check the robustness of the analysis with the RXA. The RCA takes also the imports m into account and is calculated according to:

$$RCA_{ij} = 100 * \tanh \ln \left[\frac{(x_{ij} / m_j)}{(\sum_j x_{ij} / \sum_j m_j)} \right]$$

All specialisation indicators are normalised between +100 and –100 (see Grupp, 1999). Positive values indicate an above average specialisation on the analysed technology, a negative value shows that the country is more specialising on other technologies.

Green technologies are neither a patent class nor a classification in the HS-2002 classification of the trade data from the UN-COMTRAD databank which can be easily detected. Thus, for each technology, it was necessary to identify the key technological concepts and segments. They were transformed into specific search concepts for the patent data and the trade data. This required an enormous amount of work and substantial engineering skills. Furthermore, there is a dual use problem of the identified segments. The data only indicates that there is a technological capability which could be used for ecological sustainability – not necessarily that these technologies are already implemented in a way that the environmental burden is reduced. Thus, in order to reflect that ambiguity, the term green technology, which is used in the remainder of the text, has to be interpreted as ecological sustainability relevant technology.

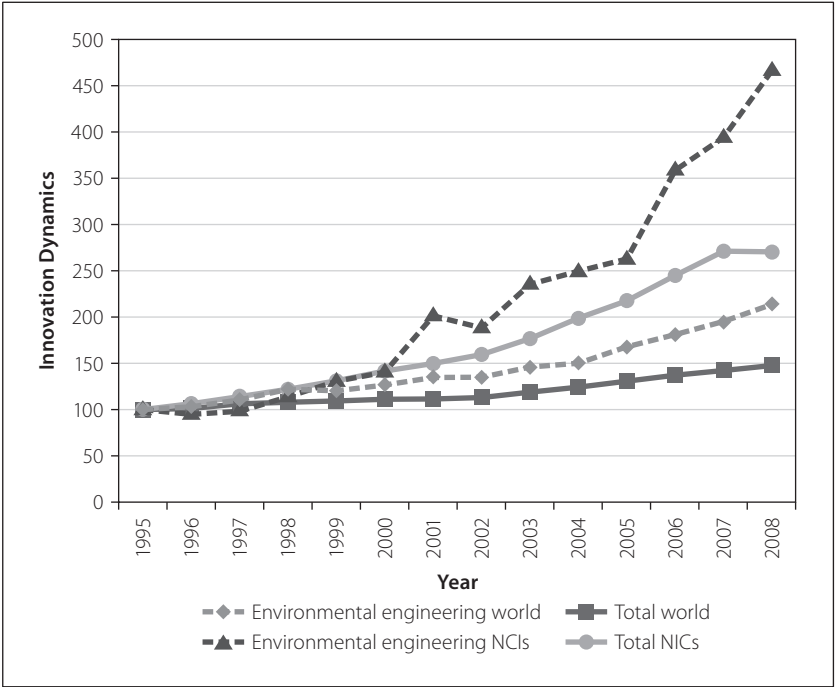
TECHNOLOGICAL CAPABILITY OF NICS IN GREEN TECHNOLOGIES – PUBLICATIONS

The development of publications can be used as an indicator for the change in the importance of scientific fields over time. Clearly the topic of environmental engineering has received increasing importance. For both, the world and selected NICs (Brazil, India, China, South Africa, Korea, Taiwan, and the other NICs in South East Asia), the growth of environmental engineering publications has outpaced the growth of all SCI publications over the last 13 years (see Figure 3). Furthermore, the growth in publications has been much stronger in the NICs than in the rest of the world. Thus, it can be argued that the topic of environmental engineering is increasingly taking a hold in the scientific community of NICs.

The development within the NICs has not been homogenous, however. This can be seen from a detailed look on the development within Brazil, India, China, and South Africa (BICS countries). The growth in the overall importance of environmental engineering publications has been accompanied by an increasing share from the BICS countries. In 2007, the BICS accounted for 12 per cent of the world's publications in this field, up from 4 per cent in 1995 (see Figure 4). However, this growing importance of environmental engineering publications is distributed very differently among the BICS countries. Especially China and India have experienced growing importance of publications in this field. The growth for Brazil has been rather modest, and there has been even a decrease in the world shares for South Africa.

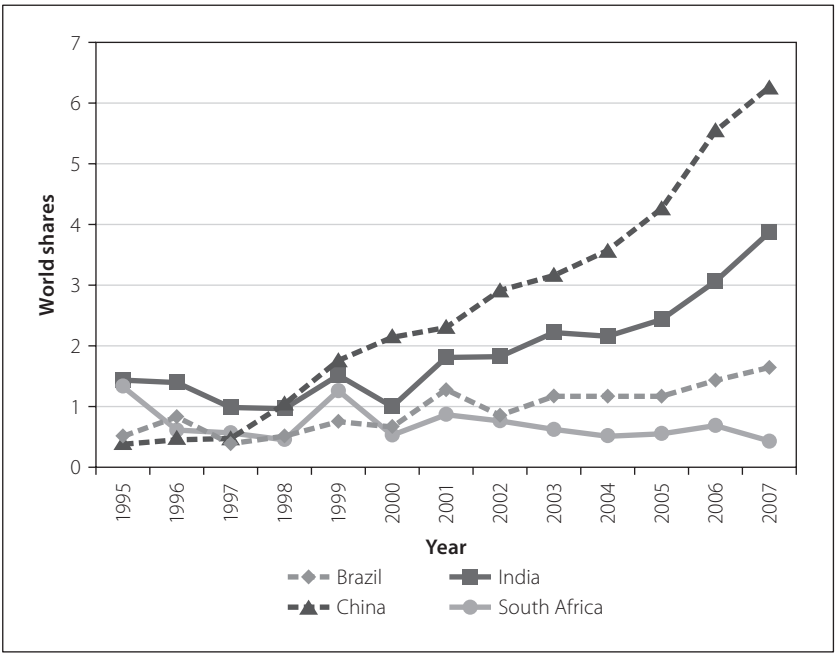
The specialisation on environmental engineering literature is measured with the RLA (see Figure 5). Looking at the development of the specialisation profile of publications, the following conclusions emerge:

Figure 3 Development of publications in the field environmental engineering in NICs and in the world (1995 = 100)



Source Calculations of Fraunhofer ISI based on SCI-Data

Figure 4 Development of world shares in the field environmental engineering in BICS countries

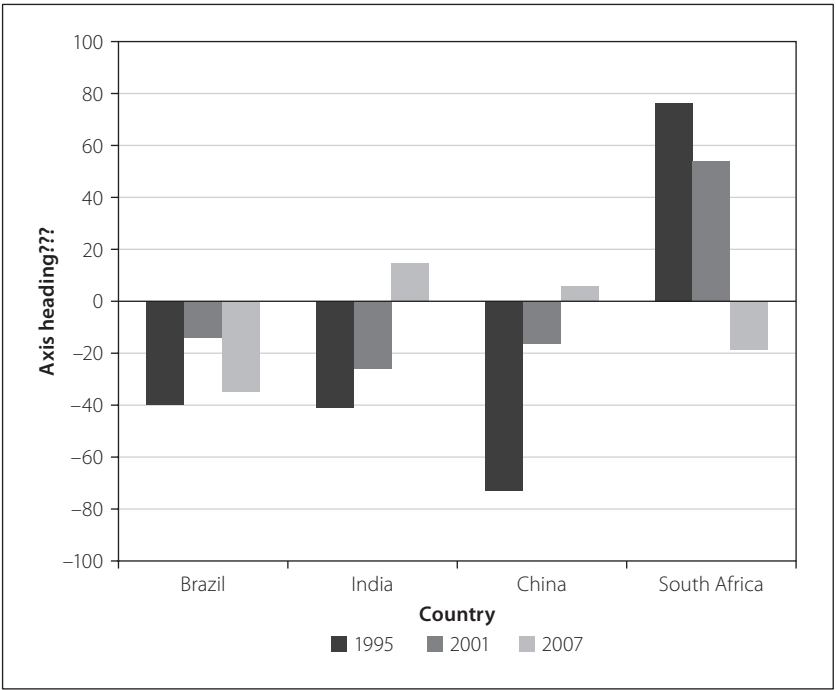


Source Calculations of Fraunhofer ISI based on SCI-Data

- China and India have experienced a strong simultaneous increase in publications as such and a growing importance of environmental engineering publications within the portfolio of publications. This is reflected by an increase in the values of the RLA.
- In Brazil, the growth of publications from environmental engineering equals the growth in overall publications; thus, the importance of the topic (and the value of the RLA) within Brazil has not been changing.
- The share of publications in all fields from South Africa constantly holds a share of 0.5 per cent of all SCI publications over the years. The share at environmental engineering publications was higher than that in the past, but has been declining. Thus, a declining of positive RLA values results indicating that the importance of environmental engineering among publications is just below average now.

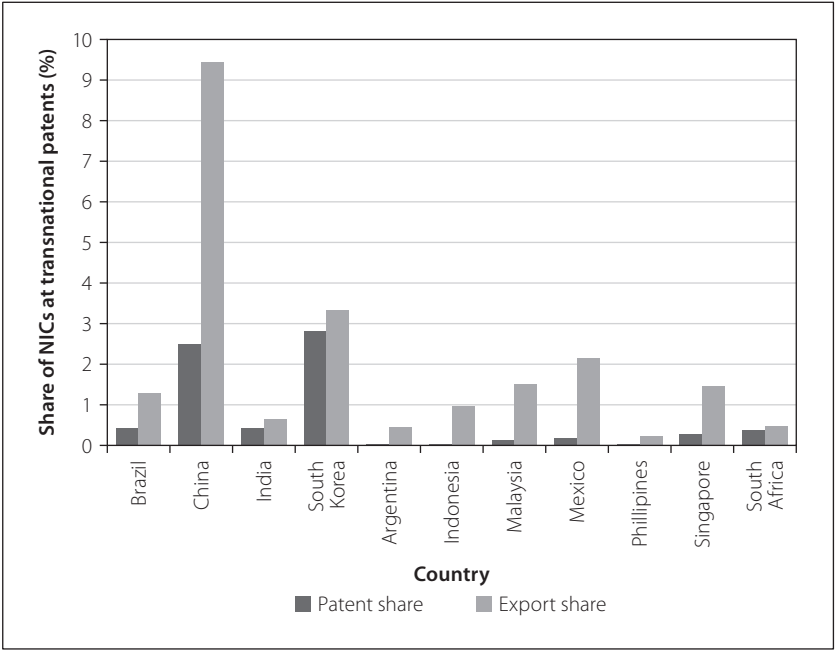
Patents and trade: The shares of the NICs at the worldwide patents for the sustainability relevant technologies are between a few per mills to between 2 per cent and 3 per cent for China and South Korea (see Figure 6). There are also some countries for which the patent indicators show very limited activity in transnational patenting of sustainability technologies. Some countries are becoming important exporters, e.g. China with a share of more than

Figure 5 Development of specialisation of publications in the field environmental engineering in BICS countries



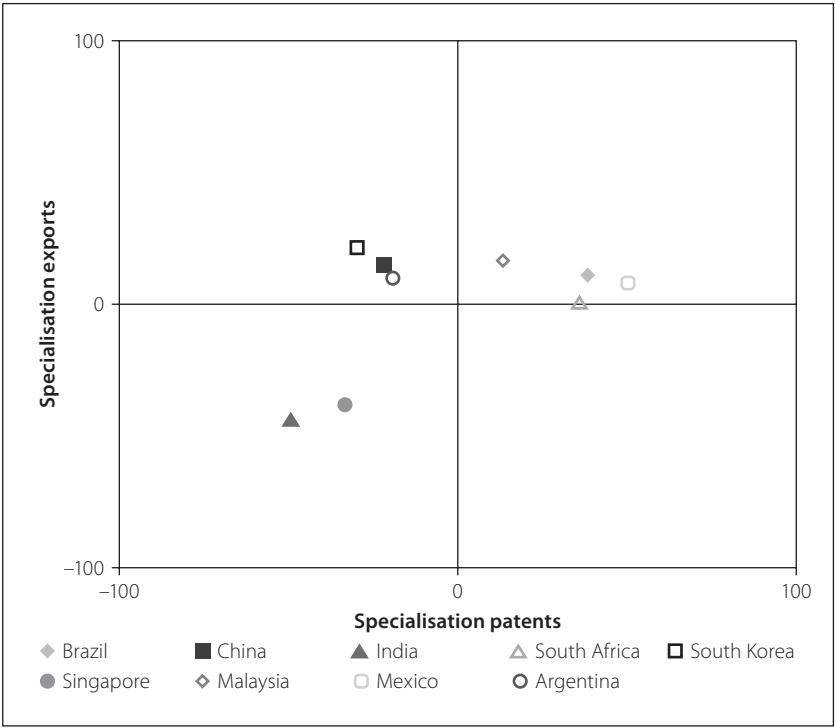
Source: Calculations of Fraunhofer ISI based on SCI-Data

Figure 6 Share of NICs at transnational patents and at world exports of green technologies in 2007



Source: Calculations of Fraunhofer ISI

Figure 7: Specialisation pattern of NICs for green technologies in 2007



Source: Calculations of Fraunhofer ISI

9 per cent at worldwide exports of green technologies. Altogether, the NICs account for about 8 per cent of worldwide patents, and more than 20 per cent of all exports of green technologies. Thus, in most NICs, the world trade shares are considerably higher than the patent shares. That shows that these countries are quite active in exporting sustainability relevant technologies, but based on a rather below average domestic knowledge base. Perhaps Foreign Direct Investment (FDI) and multinational enterprises, which produce in these countries for the world market, play a role in explaining this pattern. Furthermore, this also points towards a high importance of exports as driving force of technological catch up, a pattern which has been found by Malerba and Nelson (2008) for a number of sectors in NICs.

The importance of the sustainability relevant technologies within the individual countries is also reflected in the specialisation profile. The specialisation indicators RPA, RXA or RCA show the knowledge and technological competence in sustainability technologies within each country compared to the average of all technologies. Positive values have an above average, negative values have a below average activity of the country regarding the sustainability relevant technologies. For the countries with very limited activity in international patenting of sustainability technologies, the use of a specialisation profile was omitted. For depicting the specialisation in trade, the RXA was used. However, the overall picture does not change, if the RCA is used instead of the RXA.

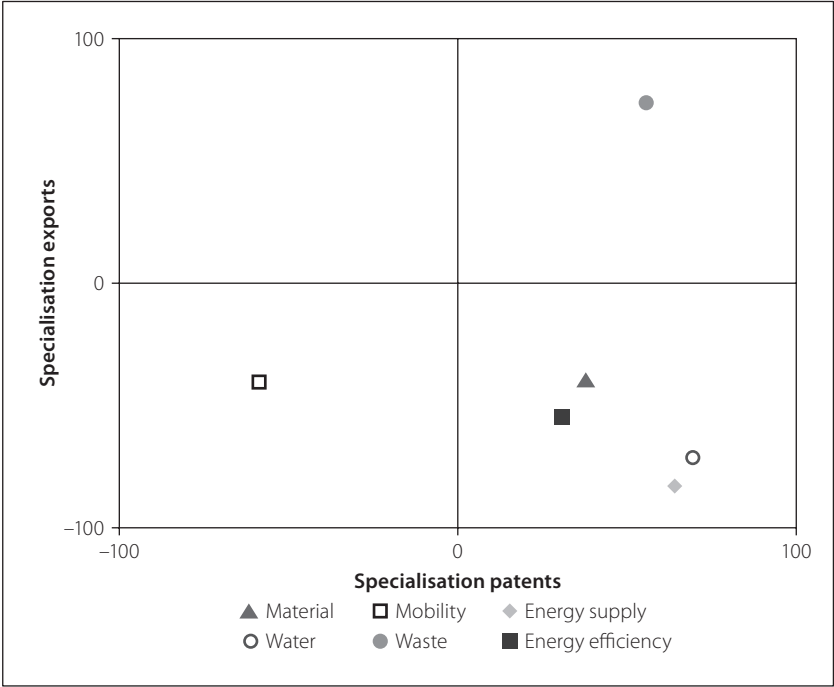
The results in Figure 7 show considerable differences between the countries:

- Brazil, Malaysia, Mexico and South Africa are specialising on green technologies with regard to patenting. Thus, the build-up of knowledge in these countries is especially strong in the fields of sustainability technologies.
- In China, South Korea and Argentina, the specialisation indices show an average importance of green technologies for exports and slightly below average for patents.
- The negative specialisation profiles for India and Singapore indicate that the economic development process in these countries is taking place more strongly in fields which are not related to the green technologies.

DISAGGREGATED ANALYSIS FOR SOUTH AFRICA

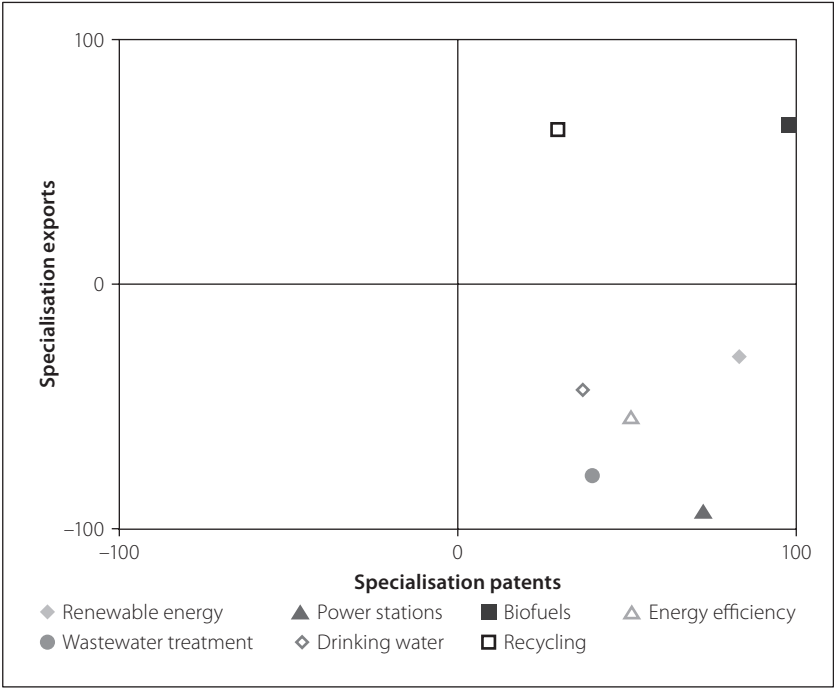
The analysis in Section 3 hides the fact that there are substantial differences within the group of green technology fields. Thus, a thorough country analysis must be performed on a more disaggregated level.

Figure 8: Specialisation of South Africa in green technology fields in 2007



Source: Calculations of Fraunhofer ISI

Figure 9 Specialisation of South Africa in selected examples of green technologies in 2007



Source: Calculations of Fraunhofer ISI

With the exception of the green mobility field, the fields investigated are characterised by an above-average activity within South Africa to accumulate knowledge (see Figure 8). The field of waste stands out on account of a positive foreign trade situation, which can be traced back primarily to sub-areas in recycling. The analysis can be disaggregating even one step further (see Figure 9). The patent specialisation indicators show that South Africa has been building up substantial knowledge in some green technologies. However, there are only few fields in which South Africa has been able to transform this knowledge into substantial export success. Thus, the challenge is whether or not South Africa will be able to improve her innovation system towards an increased ability of exporting such technologies.

A number of field-specific insights can be derived which provide important hints for future potentials:

- South Africa possesses great reserves of coal – although of lower quality than the standard. This forms the basis for domestic electricity production. South Africa is traditionally strong in coal gasification. Thus, there are important links and good pre-conditions for the future application of CCS. But it is still debatable whether, and within which time horizons CCS will become relevant there. However, the perspective of national application is also important for the future national technology development.
- Scenario analysis for South Africa underlines the huge potential for renewable energy, especially if there are enough learning effects (Winkler et al., 2009). The indicator values imply that South Africa indeed has started to build up knowledge in this area. However, the absolute level of knowledge build up is still not very high, and there is not enough transfer of knowledge into products happening. Clearly, there is a need to intensify and to integrate the knowledge build up with an increasing diffusion and an evolution of a South African renewable energy industry.
- South Africa has put emphasis also on developing biofuels (see Brent et al., 2009). However, as in other countries, biofuels have to be evaluated with regard to ecological concerns (low net energy yield) and social needs (e.g. competition for food crops): Second generation biofuels offer the potential to reduce these conflicts, and are also discussed for South Africa (Amigun et al., 2009). Because of the technical proximity of biomass gasification to coal gasification, the knowledge in the latter can also represent starting points for synthetic biofuels. From the South African perspective, this area bundles especially favourable starting conditions, as the good knowledge base is supported by already existing foreign trade experiences – Sasol is an internationally active enterprise here – and

simultaneously good links exist to the main focuses of the national innovation strategy. Indeed, the disaggregated indicator values reveal a very high specialisation of South Africa in second generation biofuel related technologies.

- The pre-conditions to set up recycling systems – among others, in the automobile industry – are considered favourable in South Africa. In the Cleaner Production Programme, South Africa has established so-called ‘Waste Minimisation Clubs’. They promote the exchange of information and experiences among companies, focusing on preventive measures to avoid waste. Due to South Africa’s competences in sub-areas of recycling, this should be a worthwhile field for further development. However, the framework conditions for recycling must be improved, e. g. as far as environmental legislation, infrastructure and buyers are concerned.
- Transportation demand has been steadily increasing in South Africa, and growing congestion and rising emissions underline the need for sustainable solutions. A great number of foreign vehicle manufacturers are present in the South African market. However, South Africa depends to a great extent on foreign countries for emission-reducing technologies, as there are few national activities to foster competence-building. There is also a need to shift the modal split in South Africa (Vanderschuren et al., 2010). The use of public transport is important, and improving South Africa’s bus system or the Gautrain project could offer important platforms for enhancing technological knowledge in these fields.
- The water field forms an independent focus of South Africa’s national innovation strategy. At the same time, South Africa demonstrates above-average knowledge capability in water, however without corresponding export success. If one considers the future challenges for South Africa in the availability of water resources, it becomes clear that this field should gain significance in the future.

The prospects of South Africa also depend whether or not the country is able to increase the build up of knowledge. Section 3 already indicated a rather sluggish development of the publications, with specialisation becoming weaker over time. Thus, the academic part of the innovation systems for green technologies seems to lose some importance in South Africa. With regard to patents of green technologies, the specialisation profile of South Africa has not been changing much over the last 15 years. This holds for the specialisation in each of the six green technology fields illuminated in Figure 8. With regard to the trade specialisation, the data is less reliable because of changes in the classification scheme and availability of time

series. Thus, for the same classification scheme, only data from 2000 on is available for South Africa for the RXA and RCA. The results indicate that – with the exception of material efficiency – all other fields experienced slight increases in the specialisation. Green technologies became somewhat more important in the export portfolio of that country, and the import dependence was diminished somewhat.

CONCLUSIONS

Global environmental sustainability requires that environmentally friendly technologies are put in place globally. Environmental economists stress the opportunities for NICs to use the latest environmentally more friendly technology, leading to a technological leapfrogging. However, this requires an interest of the NICs to push in this direction. One perspective is that these technologies help to reduce national environmental problems and to modernise the infrastructure. An additional incentive is that by moving towards green technologies, NICs might gain enough competences in order to compete on the world market in this growing market segment. Both perspectives require that NICs build up (technological and institutional) competences in the field of these technologies and their diffusion.

The various indicators do not show a clear-cut picture for NICs. There are some substantial differences within NICs, with Korea and Singapore showing the most favorable general innovation conditions and the highest absorptive capacity for new technologies in general, followed by Taiwan and China (Peuckert, 2008; Walz et al., 2008). The innovation indicators with regard to the sustainability relevant technologies also show that NICs are highly heterogeneous. Furthermore, the increase in green technology-specific capabilities varies, but is especially high in the South (East) Asian countries. Especially China has been increasing its competences lately very strongly.

Combining the different criteria, the following four country clusters can be observed (see Figure 10):

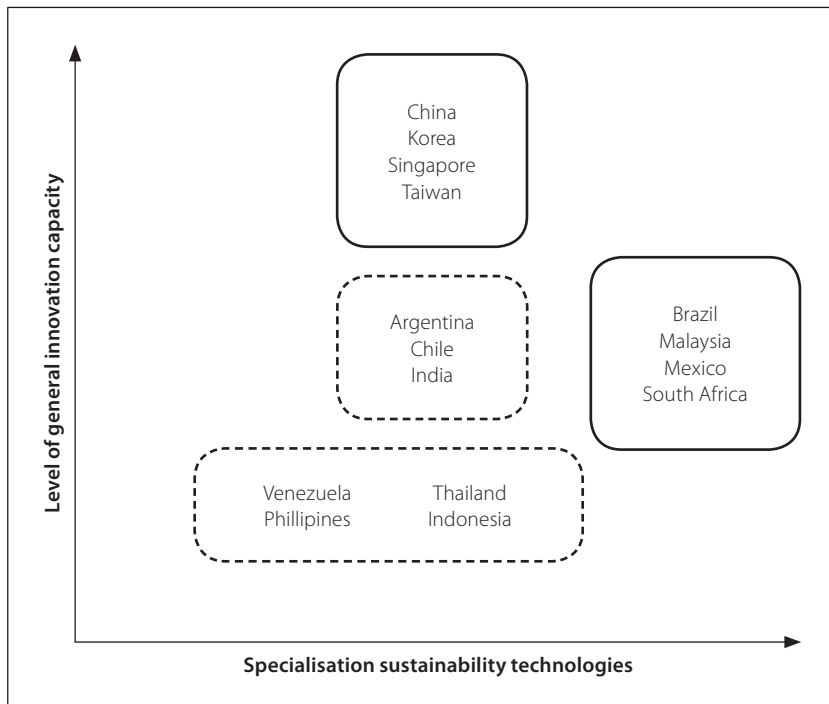
- Cluster A characterised by higher level of general absorptive capability, but without specialisation on sustainability technologies: Korea, Singapore, Taiwan, and China (especially if the overall size of the country and the dynamics of increase in competences are taken into account).
- Cluster B characterised by specialisation on sustainability with a medium overall level of general absorptive capability: Brazil, Malaysia, Mexico, South Africa.

- Cluster C characterised by medium overall level of general absorptive capability, without specialisation on sustainability technologies: Argentina, India, and Chile.
- Cluster D characterised by lower overall level of technological capability: Venezuela, Thailand, Philippines, Indonesia.

The analysis reveals that there are quite considerable differences between the green technology areas within the NICs, which are reflected in the specialisation patterns. On the more disaggregate levels of technology families and single technologies, there are indeed strong specialisations in South Africa.

Even though there is still a high dependency of technology imports in a number of areas analysed, the overall picture does not reflect a 'classical' dependency of the NICs on the traditional industrial countries as technology providers. In addition to the countries which have already obtained an above average position in some sustainability relevant technologies, the international patent activities show – particularly in China, India and Malaysia – an enormous upward trend. The same holds for the development of publications in environmental engineering. In this respect it might seem realistic that some of the NICs, e.g. China, will also become more and more successful in these technology areas in the future. Furthermore, the results

Figure 10 Overview of capability of NICs for sustainability innovations



differ with regard to the disaggregated technology areas. Thus, there are complementary strengths within NICs, which open up the potential for increased South-South cooperation in the future technology development.

However, moving towards a greater role as supplier of sustainability technologies requires additional efforts:

- Higher attention must be paid to sustainability technologies within the national research priorities. The analysis of Walz et al. (2008) shows that in none of the BICS countries (Brazil, India, China, South Africa), the research and innovation policy is especially aimed at decoupling environment and resource consumption from the processes of economic development. In all BICS countries, the general support of the innovation activity in the business sector has priority. By and large, the sustainability research within the Science & Technology policy of the BICS-countries is not institutionally differentiated. Mostly the sustainability topics are integrated into general, technology-independent funding instruments. Thus, sustainability issues do not represent an own field of the research support. This calls for research programs specifically targeted towards green technology.
- The experiences with shaping innovations in the OECD-countries towards green technology are also important for NICs and South Africa. There is no single policy instrument to push innovations. Instead a mix of policies is necessary. The incentive structure of different instruments is clearly one important issue, and the role of market based instruments to foster innovations is widely discussed. However, there is also a potential of smart regulations by standard setting to foster innovations. The effects of policies on innovations are influenced by numerous soft factors, which have to be accounted for on a case by case basis. Thus, there is no 'one size fits all' blueprint for policies to increase green innovations.
- However, there are clearly some generalisations which have to be accounted for in every case. Most important is the factor, that environmental policies are shaping the demand side of green innovations. Thus, these policies are at the same time demand driven innovation policies. Without an early application, it will be difficult to further improve green technologies as fast as necessary.
- The demand oriented innovation policy has to be coordinated with a supply oriented R&D policies. This calls for integration of the traditional R&D policies with the demand side oriented (environmental) policies, which are typically performed by different actors – a challenge which is not unique to NICs or South Africa, but which can also be found in almost every OECD country.

- Especially green technology innovations are often rather associated with sectors which are subject to specific economic sector regulation, such as energy, water, or railways. Thus, green technologies in these sectors even face a triple regulatory challenge (Walz, 2007). This leads to the conclusion that policy coordination between the different regulatory sector regimes with R&D policies and environmental policies becomes a major challenge for policy making.
- Social factors are another issue which play a very important role, but are not adequately addressed in the analysis so far. The importance of innovations in institutions, or knowledge spillovers from other sectors can be added to that list, together with the important aspects of communication patterns within the system of innovation, lock-ins, path dependency, and power structures within industry and politics (Walz and Meyer-Krahmer, 2003).

The following conclusions emerge for South Africa: The country belongs to the NICs which have already gained significant capabilities to master green innovations. Some areas, e.g. biofuels, show a very positive specialisation in both patents and exports. In some other technologies, South Africa has achieved substantial knowledge build-up, however without realising the same level of export success. This calls for improving capabilities and enhanced learning effects within the country. Some of the green technologies in the energy and climate field are covered by the five 'grand challenges', which the South African Science and Technology Policy named for its priority setting. However, enhancing development of the other green technologies requires that they are not left behind in the future R&D spending programmes.

The current trends, for example with regard to publications and patents, indicate that South Africa is not keeping pace compared with other NICs, which have been increasing their share of green technologies substantially. However, this seems to be caused not by a lowering of the importance of green technologies within South Africa, but more so by a lower overall dynamic of increasing publications and patents in all fields. This can be partially explained by the general national innovation system of South Africa (see Kaplan, 2008), in which the capabilities for green technologies are embedded. South Africa's R&D intensity has been increased, without however realising growth rates as high as in the other NICs in the past years. The availability of human resources is regarded as South Africa's greatest problem. There seems to be an ambivalent assessment of South African competences: the areas which are able to attract sufficient well-trained personnel are around the technological frontier. On the other hand, the competence of well trained personnel is not available

in many areas, which leads to problems in absorptive capabilities (see also Na-Allah and Muchie, 2009). Clearly the sector specific perspectives of South Africa in the field of green technologies can only be realised if these broader concerns of the national innovation system are successfully dealt with.

Furthermore, improving the technologies in South Africa must go hand in hand with a growing application of green innovations in the home market. Concentrating the improvement of the innovation system on R&D institutions would be far too narrow – something the South African technology policy has also been criticised for (Kaplan, 2008). Strengthening environmental regulation in South Africa must therefore be seen not as a trade-off between environmental protection and economic development, but as an instrument of demand-side driven innovation policy in one of the most dynamic growing economic sectors. Indeed, if the challenge to come up with case specific policy mixes is mastered, South Africa can participate in supplying green technologies. This would add to the perspective that achieving sustainability does not lead to diminished economic growth, but can yield additional economic benefits.

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Science for the Future

Challenges and Methods for Transdisciplinary Sustainability Research

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SUMMARY

Sustainability research is aimed at meeting the challenge of dealing with important societal problems related to the 'metabolic' processes between society and nature in a global context. Besides generating knowledge about the characteristics and dynamics of the complex processes involved (e.g. climate change, loss of biodiversity, increasing poverty and hunger), it should also contribute to normative knowledge about how to evaluate these processes and develop strategies for social change towards sustainability. An interdisciplinary composition of research teams is necessary to deal with the complexity of sustainability problems. The normative questions and the need for decisions to be made in situations of uncertainty additionally call for a transdisciplinary research design, involving actors from the life-world as equal partners. The process of integrating knowledge from different disciplines as well as from the life-world is a great challenge which needs to be met through methodological innovation. This article introduces constellation analysis as a methodological approach for bridging different knowledge claims, drawing on two case studies to demonstrate its application.

INTRODUCTION

With the 1992 United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro, the concept of sustainable development – bringing together questions of social justice with environmental issues – has gained importance in international politics. Based on these political processes, a new field of research has developed within the last decade: sustainability research. Sustainability problems are characterised by being globally interlinked, complex, synergetic, cumulative,

and highly dynamic, often marked by non-linear causal chains and significant time lags between causes and effects in the interplay between social and natural systems (Siebenhüner, 2004: 76). Due to the complex problems and the need to develop strategies for a rather deep social and ecological transformation of society, sustainability research is often organised as inter- and transdisciplinary research. This research type faces the challenge of integrating knowledge and methods from different scientific disciplines and of integrating both life-world and scientific knowledge.

Sustainability research can be understood as being part of a transformation towards a new mode of knowledge production, called 'mode 2' (Nowotny et al., 2001; Gibbons and Nowotny, 2000, Gibbons et al., 1994), in contrast to disciplinary science ('mode 1'). Science of this type acknowledges the appearance during the last few decades of societal problems of a new quality, which cannot be dealt with adequately solely via disciplinary science (Schmidt and Grunwald, 2005; Mittelstraß, 2005; Jahn, 2003; Lange, 2003; Bechmann, 2000; Brand, 2000). Other prominent fields for inter- and transdisciplinary approaches are health, risk, environmental and innovation research (Pohl and Hirsch-Hadorn, 2008; Schön et al., 2007).

The basic demand of inter- and transdisciplinary approaches is to integrate different perspectives and knowledge successfully throughout the whole research process (Pohl and Hirsch-Hadorn, 2008). Although certain scholars have tested methods and tools for sustainability research over the last years (Schophaus et al., 2004; von Blanckenburg et al., 2005; Pohl and Hirsch-Hadorn, 2008), innovative methods in this domain are not yet sufficiently explored. The need for a middle-range concept which is able to bridge different areas of expertise and enable the understanding between persons with different scientific and professional backgrounds, rationalities and logics of action has led to the development of constellation analysis at the Center of Technology and Society of the Technische Universität Berlin (Schön et al., 2007)¹. In this paper we introduce constellation analysis as a bridging concept, demonstrate its applicability for different purposes and conclude how it could be used for sustainability and innovation research in industrialized and emerging countries.

CHARACTERISTICS OF SUSTAINABILITY RESEARCH AND METHODOLOGICAL CHALLENGES

(A) CHARACTERISTICS OF SUSTAINABILITY RESEARCH

Sustainable development is a political concept which is based on the normative premises of intra- and intergenerational justice and compatibility

with the limitations of natural resources. The operationalisation of these premises in concrete guidelines for future development strategies is a controversial issue in society as well as in science. The understanding of 'sustainable development' therefore has to be clarified in each process of sustainability research, the scientist being only one of the societal actors who position themselves with their interests and values in a field of conflicts. Since problem definition in sustainable research is directly linked to normative values, science alone is not competent enough and legitimised to realise research and draw on recommendations without consulting societal actors (Nölting et al., 2004; Schäfer, 2007).

Further, sustainability research is characterised by taking up life-world problems in the intersection of society and nature which urgently call for political action and coping strategies, even if the knowledge available about causal interrelations and the effects of interventions is highly uncertain (Bechmann, 2000).

A methodological consequence of these characteristics is the necessity for the integration of knowledge from different disciplines as well as the systematic integration of life-world knowledge (Becker and Jahn, 2006: 292–308).

Brand (2000: 24) describes the function of inter- and transdisciplinary sustainability research as follows:

Transdisciplinary sustainability research aims to contribute to the solution of different problems of sustainable development. The premise is that these solutions cannot be worked out alone by science and not by highly specialized disciplines. On the contrary, sustainability problems partly result from the dynamics of scientific, technical and societal processes of differentiation. However, solutions also cannot be found without highly specialized science – but only through new, problem-oriented, interdisciplinary connections being created.

In sustainable or transdisciplinary research a differentiation is made between three types of knowledge that are generated (Cass/ProClim, 1997; Maier Bégé and Hirsch Hadorn, 2002; Nölting et al., 2004; Pohl and Hirsch-Hadorn, 2007):

- *Systems knowledge*: about the characteristics and dynamics of processes and the interconnections between ecological, economic, social and cultural aspects;
- *Normative or target knowledge*: helps to evaluate the sustainability of societal transformation;
- *Transformation knowledge*: helps to develop strategies for societal transformation process.

All three types of knowledge are linked with each other and have to be analysed interdependently (Hirsch-Hadorn et al., 2002: 15). There are different reasons for integrating non-scientific or popular knowledge into the generation of each of these types of knowledge. Regarding the generation of systems knowledge, exchange with practitioners allows insight into interconnections and limitations that can only be experienced by being an actor in the field concerned. Including other forms of knowledge also makes it easier to obtain an impression of the different scales (local, regional, national, global) and the multiple, interactive, and cumulative character of certain problems (Siebenhüner, 2004: 77).

As mentioned above, the need for integration of different societal perspectives seems especially evident concerning the generation of normative or target knowledge. Scientific research can help to identify different interests and moderate the process of discussing transformation goals, but it cannot define normative premises on its own. Defining critical loads or threshold values, evaluating risks, dealing with uncertainty, choosing transformation goals and indicators – all these steps are based on normative decisions, which imply conflicts of interests and values. Transformation goals only have a chance of being implemented if they are accepted by those who will be affected. Acceptance requires integrating these actors in the transformation process at an early stage (Brand, 2000: 20).

Concerning transformation knowledge, exchange with practitioners is essential for the development of solutions or strategies that are context-specific and will be relevant in practice. The chances of success for necessary changes improve if those groups affected are not only integrated into the definition of transformation goals, but also into the construction of transformation strategies and measures (*ibid.*).

(B) METHODOLOGICAL CHALLENGES OF INTER- AND TRANSDISCIPLINARY RESEARCH

Interdisciplinary research teams have to integrate different methodological approaches as well as disciplinary knowledge related to their specific research problems. At the bottom, this cognitive integration process involves linking empirical data and theoretical concepts from very different backgrounds, that is from social and natural sciences (Nölting et al., 2004). One of the main difficulties for interdisciplinary cooperation is to differentiate between the different disciplines, their technical terms and languages. Researchers perceive this time-intensive process as the main difficulty and even barrier to interdisciplinary research (Lowe and Philippson, 2009; Böhm, 2006; Bromme, 1999; Klein, 1996).

The problems of mutual understanding are even more evident in transdisciplinary projects which aim at integrating 'life-world' knowledge

throughout the research process. Practitioners and scientists act on the basis of very different rationalities and logics of action – besides not being groups of homogeneous actors. While, for example, the scientists are interested in in-depth analyses which allow reliable conclusions, practitioners many times are obliged to take short-term action. They need prompt advice which can easily be transformed into concrete strategies. Limoges (1993: 420) states that each of the researchers and practitioners locates the problem in an alternative ‘world of relevance’. This diversity in perspectives must be taken into account while identifying and structuring the problem and while developing and testing means to deal with it. Several authors agree that the first step in mutual learning and integration is to acknowledge the diversity of perspectives and to explore and clarify their differences (Giri, 2002; Loibl, 2005; Loibl, 2006; MacMynowski, 2007).

Pohl and Hirsch-Hadorn (2007) differentiate three phases of a transdisciplinary research process: a) problem identification and structuring; b) problem analysis; and c) bringing results to fruition. Furthermore, they have introduced four principles for carrying out transdisciplinary research: a) reduce complexity by specifying the need for knowledge and those involved; b) achieve effectiveness by contextualization; c) achieve integration through open encounters; and d) develop reflexivity through recursiveness.

The first principle – specifying the need for knowledge – implies deciding which research questions need to be addressed by a project and determining the corresponding conditions. To this end, it is necessary to find out what kind of systemic perception underlies a project, what normative targets it has set itself, and what potential societal transformations it aims at. The second principle states that impact-related contextualisation of a project consists in making the research results accessible to those concerned. For this aim, it is essential to reformulate the results differently for specific target groups. The third principle of integration by being open to encounters frames the aspect we already mentioned above: It implies perceiving one’s own perspective as only one among several others, and accepting other views as potentially equally relevant to one’s own. Only thus can constructive discussions about the potential of various perspectives to contribute to a common undertaking take place and be further developed. The fourth principle, recursiveness, means that the research process is shaped in such a way that theory and methods are repeatedly tested by applying them to practice and that underlying assumptions can be modified if they are found to be inadequate. According to Pohl and Hirsch-Hadorn (2007) such a recursive design is a pragmatic way to prevent a project from becoming stuck due to uncertainty or the preliminary state of knowledge.

Researchers in this field have to translate the challenges of reducing complexity, contextualisation, integration and recursiveness into the formulation

of concrete methods. Over the past decade, a more intense reflection on success factors and adequate methods and tools for inter- and transdisciplinary cooperation processes has emerged (Mogalle, 2001; Schäfer and Boeckmann, 2004; Schophaus et al., 2004; Strübing et al., 2004; Bergmann et al., 2005; von Blanckenburg et al., 2005; Pfriem et al., 2006; Pohl and Hirsch-Hadorn, 2006; Boeckmann et al., 2007; Pohl and Hirsch-Hadorn, 2008). Many of these publications concentrate on aspects of cooperation management and offer recommendations for an adequate organisational structure of these processes. Others introduce different types of participative tools which allow integrating life-world knowledge (e.g. citizen juries, scenario workshops, future conferences) or deal with conflicts concerning transformation strategies (e.g. mediation, consensus conferences). Up till now, however, few methods have been developed which facilitate obtaining insight into and allowing the structuring of the perspectives of actors with different backgrounds – be it different disciplines or scientific versus life-world backgrounds.

CONSTELLATION ANALYSIS: A BRIDGING CONCEPT FOR INTER- AND TRANSDISCIPLINARY RESEARCH

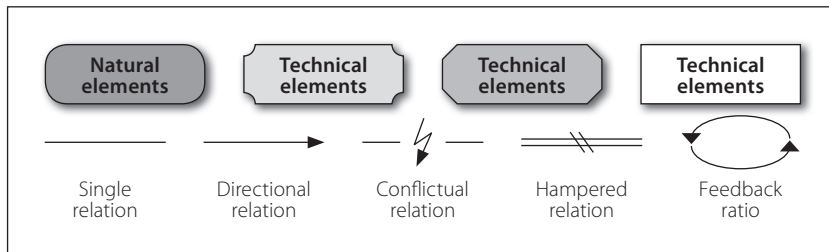
To meet some of the demands for carrying out inter- and transdisciplinary research, constellation analysis was developed as a bridging concept for mutual understanding between different disciplines and between science and life-world actors (Schön et al., 2007). Here, a bridging concept means an approach comprising several analytical categories which different disciplines can relate to.

CORE ELEMENTS OF CONSTELLATION ANALYSIS

The complex problems treated in sustainability and innovation research are understood as constellations which are characterised by interactions between different factors, dynamics and contexts. A constellation is mapped by an interdisciplinary or transdisciplinary research team starting from its central elements. Adding new elements, research team members from different disciplines and/or lay experts judge the relevance of successive elements proposed, initiating a discursive mapping process. The team agrees on a common interpretation of the relevant elements and relations within the constellation and the influences between them. Constellations consist of different types of elements, differentiating social actors, natural elements, technical elements and systems of signs. Social actors can be individuals as well as social groups that are actively involved in the decision-making process. Technical elements include all technical artifacts. Natural elements characterise substances and

resources, animals and plants as well as other natural phenomena. Systems of signs include ideas, concepts, ideologies, laws, communicative acts and images. Taking into consideration early actor-network theory concepts (Latour, 1987), the central focus of this method is treating the heterogeneous elements as being equal. This emancipated consideration of the elements allows a non-hierarchical interdisciplinary cooperation which does not differentiate in terms of 'leading' and 'auxiliary disciplines'.

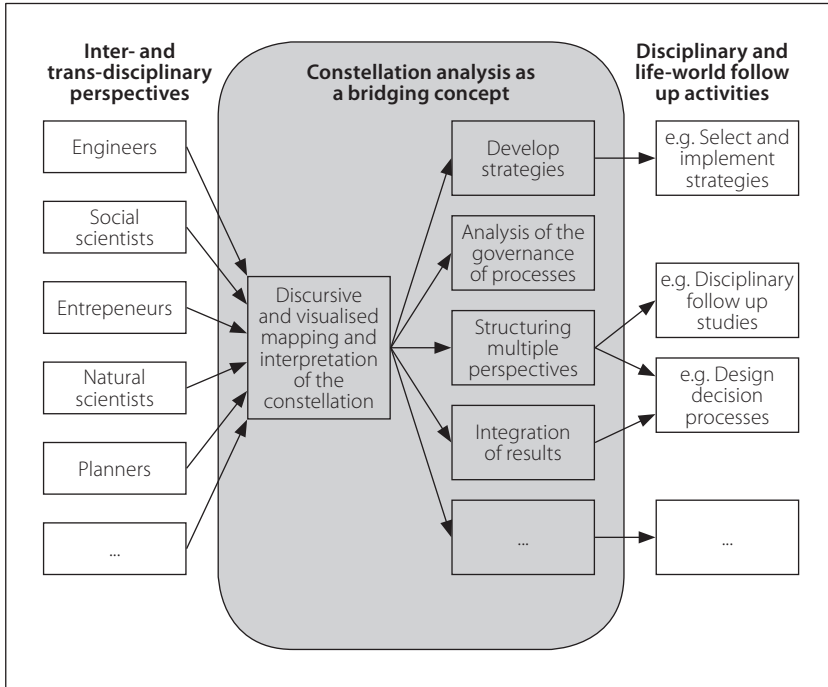
The four types of elements and the relations between them are characterised by symbols:



After identifying the central elements, the interrelations between them are analysed and mapped. This step obliges the actors involved to refer to each other's perspective. Clarification of the relations between the elements is necessary to be able to understand the structure and logic of a constellation. The next step consists in describing the dynamics of a constellation. The key element of the method is the visualisation of the constellation in the form of a graphic image. Transforming an inter- and transdisciplinary discussion into a graphic representation enhances mutual understanding by relating different perspectives to each other and clarifying points of consensus and dissent. Visualising complex constellations makes it easier to depict them in several steps and to analyse and discuss them collaboratively, both within the research team and with lay-actors. Visualisation therefore supports language in the process of mutual understanding as an important supplementary medium.

So far, constellation analysis has been implemented with different objectives: (a) mapping of the diversity of perspectives; (b) development of strategies on the basis of a constellation mapping; (c) analysis of the implementation and the impact of policy measures on the structure of a constellation over a longer period of time; and (d) integration of results within an interdisciplinary research project.

All of these objectives have in common that the step of constellation mapping was the prerequisite for inter- and transdisciplinary analysis by providing structuring and systematisation. Figure 1 illustrates the function of the constellation analysis as a bridging concept for mutual understanding.

Figure 1 Constellation analysis as a bridging concept

Source Translation from Schön et al. (2007).

APPLICATION OF CONSTELLATION ANALYSIS: TWO CASE STUDIES

The following sections introduce two case studies applying constellation analysis in sustainability research, featuring the main characteristics of inter-disciplinary and transdisciplinary sustainability research. The first focuses on the development of the wind energy sector in Germany and tackles the implementation and impact of technological innovation and policy measures on the structure of a constellation over a period of thirty years. The second case study investigates the diversity of perspectives on flood management in the Middle Elbe Region in Germany, wherein the views of different actor groups involved in flood management are mapped focusing on values and rationales.

Case 1 – The German wind energy sector: mapping an innovation biography

The German wind energy sector has seen rapid growth during the last 40 years and was marked by a dynamic process of innovation, with Germany having become the world's leading wind energy producer. A research project² proceeded from the hypothesis that, in the course of the innovation of wind energy, both the network structure of decision makers and the application of technology shifted (Ohlhorst, 2009; Bruns et al., 2008). It was assumed that technical and natural elements are closely linked to institutional and

social developments and that this heterogeneous constellation has been permanently reorganised.

The relations between the main elements and the impact of regulation measures were investigated employing an inter- and transdisciplinary research process. The core agents and the main forces of change were identified and their characteristics described. The mapping process was guided by the two questions: Firstly, which decision makers and interests influenced the innovation process? Secondly, do other aspects, such as technology, economic, ecologic, social, institutional or natural conditions, play an important role? By mapping constellations of different development phases of the sector, the study was able to analyse whether it was the role of the actors or other elements that had changed over the years. The core question was: What conclusions can be drawn from change of these constellations for governing innovation processes?

Figure 2 Phases of the development of the German wind sector

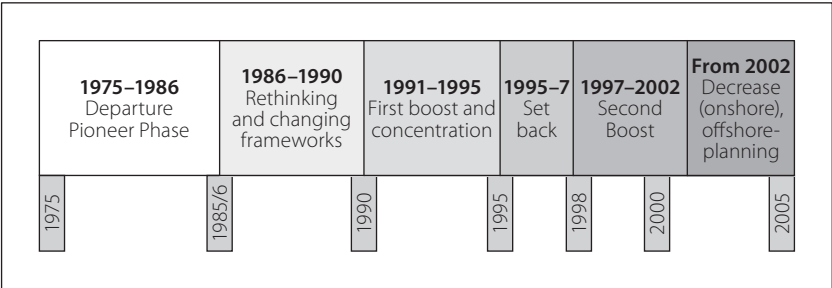


Figure 2 summarises the development of the German wind energy sector in different phases. The energy sector in the 1970s was dominated by centralised energy suppliers which used fossil energy sources or invested in nuclear energy plants. Motivated by the oil crises and the environmental as well as the anti-nuclear movements the development of the wind energy sector began as a niche. From 1975 to 1986, wind power was generated mainly for private and local requirements, for example by farmers, in small, decentralised plants.

Between 1986 and 1990, in the second phase, there was much change in the field of energy policy and the surrounding conditions. That is, in 1986 the reactor catastrophe of Chernobyl occurred, the Brundtland-report pointed out the limits of growth and created awareness about the problem of climate change. The operator-communities of wind energy producers were growing. That is, at that stage, there were not only single turbines, but also the development of the first wind farms, comprising three or more plants. Substantial support programmes and subsidies led to technical progress in the sector. As an external influence, particularly the development of the wind energy sector in Denmark became a role model and, as such, exerted a driving force.

From 1991 until the mid 1990s, an initial 'wind energy boost' occurred in Germany, mainly because of the 'Feed-In Act' for electricity and also because of the governmental '250 MW-support program'. Figure 3 shows the constellation of the wind energy sector in this phase.

Governmental interventions in this phase were embedded in a consistent strategy: The energy markets were opened and liberalised and the national government had important ecological and climate-protection aims. The governmental measures were supported by a broad alliance of actors, some of which had newly entered the constellation: investors, operators, producers, politicians and lobbyists.

However, the governmental actions were not the only driving forces in this phase, as they interacted with other factors. Wind energy plants became appealing for capital investment. The local operator communities became increasingly differentiated, using their expertise to expand and professionalise. The professionalisation of the operator companies was crucial for the wind energy boost in the early 1990s.

In middle-1990s, the fourth phase, Ohlhorst identified a break in the development of wind energy in Germany. The power supply companies and their associations expressed doubts about the conformity of the Feed-In Act with European Union law. One result was an uncertainty for investors and a slump in sales of wind turbines. Simultaneously, the acceptance of wind power plants decreased because wind turbines got bigger, developing to big industrial installations. The national governmental initiatives stagnated:

- The support programmes expired, and the Feed-In Act was massively attacked by the energy-supply industry. Their representatives intervened with legal measures and claimed that the law did not comply with European Union subsidy regulations.
- The national ministry for economic affairs considered a reduction of the feed-in tariffs.
- The national administration court decided that wind power plants were not to be considered as privileged construction projects in the building law – countering their assessment in the ongoing debate.

The uncertainty increased and affected many actors, such as authorities, banks, investors and producers. There were also technological factors which had a retarding effect: Due to rapid innovation cycles, some of the plants were not well constructed. Since these plants were prone to errors and dysfunction, they harmed the image of the whole technology.

To sum up, the motivations and aims in this phase seemed to be ambivalent and partly contradictory, even on the part of the state actors, so the constellation appears inconsistent.

Figure 3 Constellation of the energy sector from 1991 to 1995

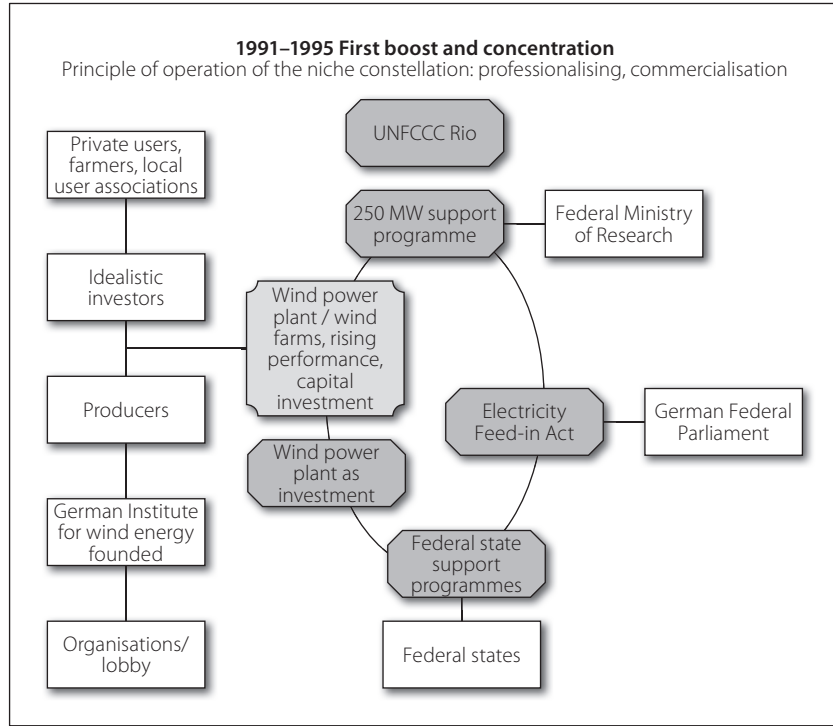


Figure 4 Constellation of the energy sector from 1995 to 1998

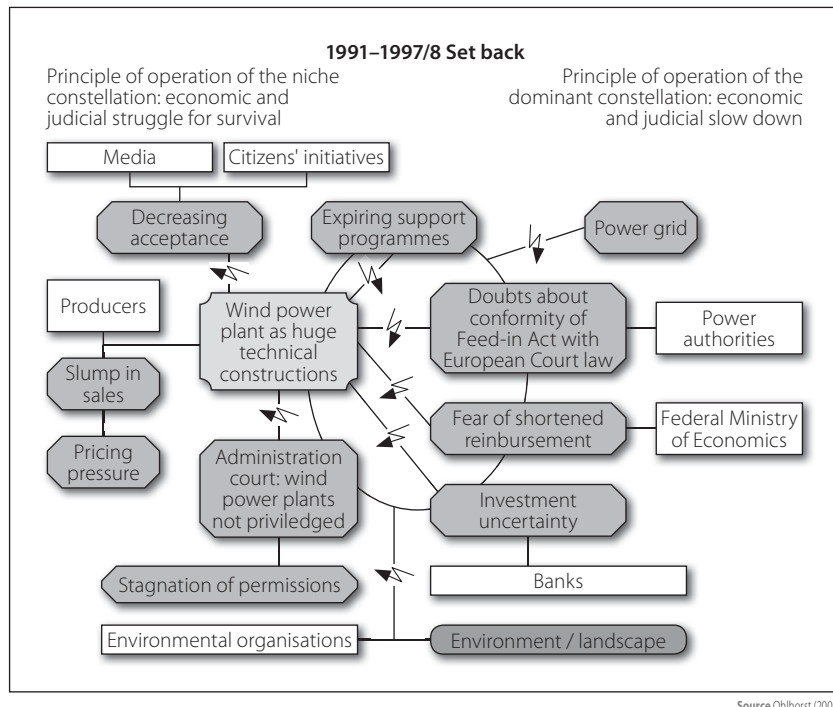


Figure 4 illustrates changes of the constellation in this phase. The last two phases were mapped in a similar way. At the end of the 1990s, a second boost of wind energy deployment started. The European Court of Justice decided that the Feed-In Act complied with European Union law, and wind farms again became attractive for capital investment. The new Feed-In Act, called the 'Renewable Energy Sources Act,' provided long-term feed-in tariffs and planning reliability for the operators. Furthermore, increasing the percentage of renewable energies played a crucial role concerning the political targets in the field of climate protection. The state initiatives responded adequately in providing the means to overcome the obstacles of the preceding phase. However, there were also some unintended impacts of the state measures: In some regions there was an uncontrolled growth of wind power plants and conflicts between different ecological targets (nature protection and climate protection) became more obvious.

In the sixth phase, from 2002 to now, the constellation split into two parts: the onshore and the offshore wind energy sectors. Onshore, wind energy development in Germany has been decreasing. Despite much planning, only a few offshore German wind turbines have been realised in a North Sea wind energy test site.

Employing the process of mapping and analysing the above constellations, formulated with the help of scientists from different disciplines and actors from the wind sector, several results became evident:

- By visualising the different perspectives it was possible to gain a more detailed picture about the relevant elements and relations. The process of assembling mutual consent about the structure of the problem and its characteristics was supported by mapping the constellations.
- Carrying out the analysis together led to a common understanding of the main influential factors and awareness that successful innovation processes depend on parallel progress being achieved in various dimensions (e.g. technology, social aspects, politics, and favorable surrounding conditions).
- The constellations of different phases showed that the state had changed its interests and aims in the course of the process. The figures made the strategy-change of state actors and institutions perceivable for all actors.
- The analysis showed that different regulatory measures made sense in different parts of the constellation at a given time and level of the innovation process. Used as a scenario instrument, the constellation analysis was able to help in identifying the phases and crucial points for successful governmental action.

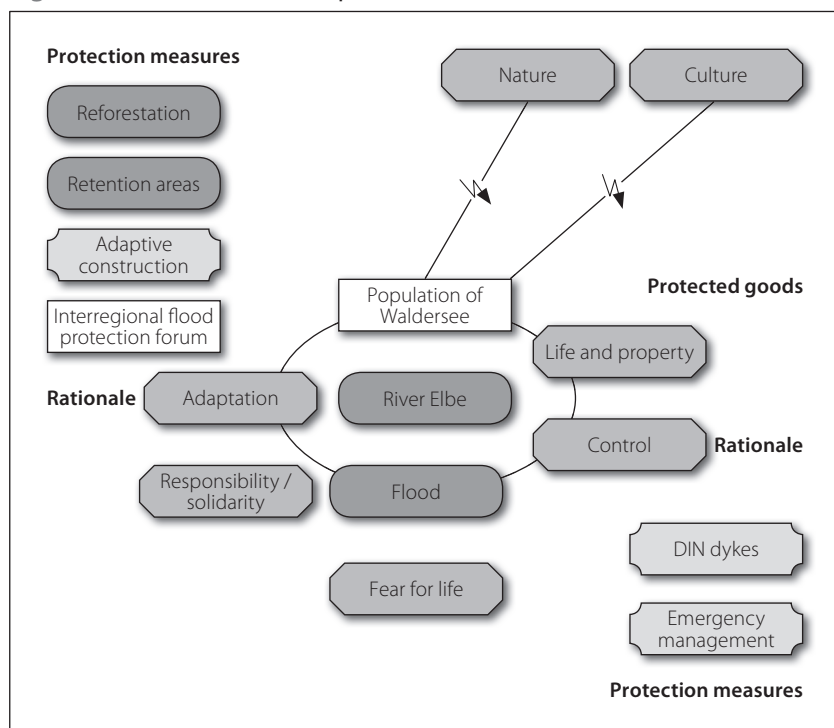
- By participating in the analysis, the actors of the wind energy sector were able to understand the sector's 'innovation biography' better, which helped them to draw conclusions for further development processes.
- From a scientific point of view, understanding innovation processes in one sector can be useful for analysing other sectors (e.g. solar energy, energy from biomass), identifying their commonalities and differences.

Case 2 – Flood management: understanding different perspectives for strategy development

The second case study draws upon a transformation process in flood management in the aftermath of extreme flooding of the Elbe and Mulde rivers in Southeast Germany in August 2002 (Kruse, 2010). After the flood, which had resulted in substantial damage to infrastructure, private houses and agricultural land, all groups of actors stated that there had been mistakes in the past and demanded a change of strategy for flood protection. However, there was no common understanding of what should change and how this change should be brought about. Discourse about the flood and how to react to it quickly became very emotional, and soon the different actors and actor-groups seemed to separate into two camps: those who wanted a change of strategy and to give more space to the river, and those who wanted to achieve more security through technical flood-protection measures. As their positions hardened, it became very difficult to lead a constructive, solution-oriented dialogue.

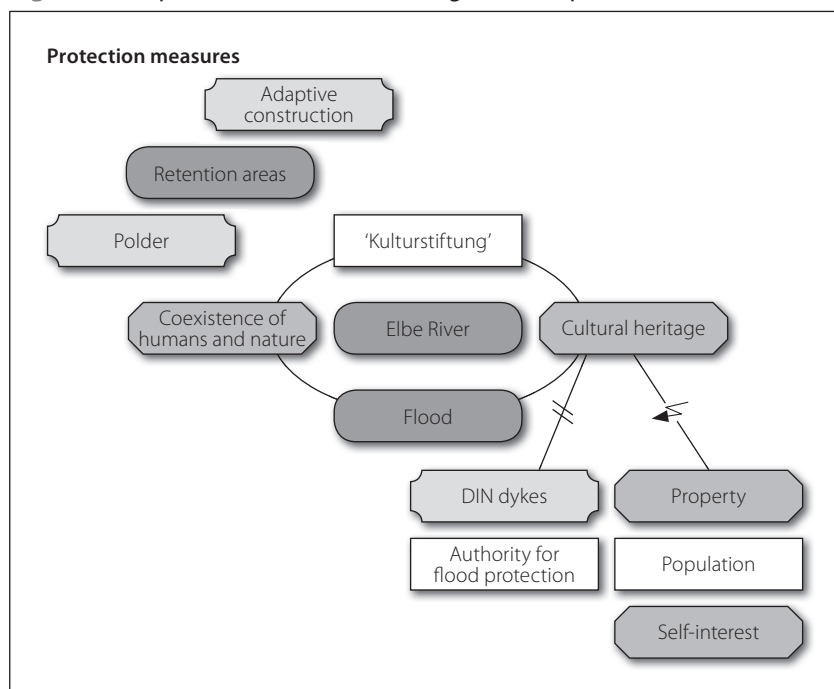
A research project³ tried to enhance mutual understanding by mapping the different perspectives on flood-protection strategies in the Federal State of Saxony-Anhalt (Forschungsverbund 'Blockierter Wandel', 2007). A comparison between the different perspectives was intended to illuminate the differences between positions, the nature of real or perceived conflicts and key obstacles to the implementation of flood-protection measures. The constellations are based on qualitative interviews with representatives of all the groups involved in the flood-protection scheme under study. The interviewees tried to clarify what they would consider the main aims of and rationales for flood protection (what they would call the 'right' measures). Within the research project actors like the Authority for Flood Protection of Saxony-Anhalt, several local communities, environmental organisations and the authority for cultural heritage (Kulturstiftung) were interviewed. Based on the interviews and documents, the perspective of each actor group involved in the flood-management discourse was mapped with the help of constellation analysis. The interviewees were then consulted several times in order to discuss the maps and the initial findings. They had the

Figure 5 The 'Waldersee-Perspective'



Source Kruse (2008)

Figure 6 Perspective of the *Kulturstiftung* on flood protection measures



Source Kruse (2008)

opportunity to revise or change the map, to comment on the visualisation, or express their own interpretation.

Figures 5 and 6 show perspectives of two different actors concerning possible strategies of preventing floods in the future: The first is one of the communities (Waldersee) which was severely affected by the flood (see Figure 5) and the second the federal authority for the protection of historic buildings and monuments (Kulturstiftung), which is illustrated by Figure 6.

For the population of Waldersee, the primary aim of the protection-measures is to prevent their livelihoods and property from future flooding. They acknowledge that nature and culture are important goods, but if their protection conflicts with the protection of livelihoods and property – which happened in several cases in the restoration and rebuilding of the protective infrastructure – they are seen as subordinate. In the opinion of the Waldersee community, the rationality of flood protection should primarily be to control and regulate flood events through a secure dyke system and improved emergency management. However, adaption to flood events was seen as a back-up strategy, on the assumption that technical means cannot prevent a catastrophe entirely.

The population of Waldersee has introduced a wide range of proposals for future approaches to flood protection. These include both technical protective means, such as dykes and emergency management, and preventive measures, such as reforestation, the creation of retention areas and the initiation of an interregional flood-protection forum.

The perspective of the Kulturstiftung reveals another characteristic of the debate. The Kulturstiftung's main focus is on destructive flood protection measures rather than destructive flood events. Heading the conservation of the UNESCO world cultural heritage site 'Dessau-Wörlitzer Gartenreich' (known as 'The Garden Kingdom of Dessau-Wörlitz'), which lies in the floodplain of the river Elbe, the Kulturstiftung mainly wants to protect its historical intactness. As a result, it has criticised all flood-protection measures that proposed to reinforce, and thus to alter, the ancient dykes, which are designated as historic structures. It also accused the local population of according their property and selfish interests a higher status than the national, common interest in cultural heritage. Furthermore, it insisted that the Authority for Flood Protection ought not to adhere to the standard of dyke restoration in cases of designated historic dyke structures.

According to this body's perspective, flood protection should follow the rationale for the coexistence of humans and nature and should focus on natural flood protection by building polders, widening retention areas and supporting adaptive building strategies.

Figures 5 and 6 outline the perspectives of the Waldersee community and the Kulturstiftung respectively on flood protection measures. Mapping

the different perspectives was the first step of the research project. To enhance mutual understanding, the maps of other actors' perspectives were then compared and discussed with the interviewees. During these feedback discussions most of the actors interviewed were very interested in the perspectives of the other actor groups and often exhibited a 'light-bulb' effect: 'I never thought they saw it that way!'. This was the basis for organising a workshop bringing the different stakeholders together at one table and facilitating dialogue rather than confronting different positions.

Applying constellation analysis in this project had the following benefits:

- Mapping the main elements and the interrelations between them helped the research team to get a first impression of the constellation as a starting point for transdisciplinary dialogue.
- With the help of this method, it was possible to clarify different perspectives on flood-protection strategies of the actors involved. The graphic representation was a good tool for discussing the different perspectives with the actors in an open and transparent way.
- Comparing the different perspectives was helpful for identifying commonalities and sorting out the crucial points for discussion and mediation. The results of this analytical process could then be used by actors responsible for the design of future flood-protection strategies.

The research project concludes that this way of mapping multiple perspectives can prepare and facilitate dialogues and negotiation processes, which previously have been blocked. It can be a constructive means for reaching a common problem definition, as a first step in conducting participatory negotiation.

CONCLUSIONS

Constellation analysis has proved to be very helpful for achieving mutual understanding in inter- and transdisciplinary research projects and can be applied with different objectives. The possible applications are discussed along the three phases of transdisciplinary research processes and the four principles which were introduced in Section 2 (Pohl and Hirsch Hadorn, 2007).

We have shown that constellation analysis can be applied with good effects for problem identification and structuring. The graphic representation involved facilitates discussion of participants from different scientific and professional background and helps to structure the problem according to the main elements and their relations. The defined set of elements – technical,

natural, social and symbolic – supports the participants in describing ‘the whole picture’ and inhibits them from holding on to uni-dimensional or incomplete framings of the problem concerned.

The advantages described are also relevant for the second phase of problem analysis. By describing the relations between the elements in detail and identifying conflicting, hampered or feedback relations, systems knowledge is deepened. Interdisciplinary and transdisciplinary dialogue is crucial for a thorough analysis of the problem. Besides identifying the main actors and policy measures which are influential in a constellation – which would be the focus of social-science analysis – it calls attention to the influence and agency of natural and technical elements. On the other hand, engineers and natural scientists, who might focus solely on technical aspects and the limits of natural resources, get an impression of power relations and conflicting interests. These can be decisive for the success of an innovation or for applying transformation strategies. Equally, actors from the life-world can be motivated to reflect upon their own positions while being involved in the mapping process. They are likely to widen their perspectives by getting to know the patterns of interpretation of actors from other contexts.

Constellation analysis facilitates a systematic approach to problems in sustainability research within three steps: firstly, identifying the main elements and the interrelations between them; secondly, describing the structure and characteristics of the constellation; and thirdly, exploring the dynamics of the constellation. Depending on the question of interest, it can be helpful for the analysis to compare constellations from different actors or from different phases.

A common understanding of the problem or the achievement of making different perspectives transparent can facilitate to bring results to fruition (transformative knowledge). The constellation analysis can help to simulate the change of certain elements (e.g. creation of a certain law or technological innovation) and the differences in the relations between certain actors. Scenarios of applying different policy measures and their effects on the whole constellation can be set up and compared. The actors involved receive support in decision making by visualising certain consequences considering all unintended side effects. Problem analysis can also facilitate to identify missing elements or relationships.

Regarding the four principles that guide transdisciplinary projects, constellation analysis contributes to integration of multiple perspectives throughout the whole process. By visualising complex interrelations and using a common language which can be understood by all disciplines and life-world actors, it also contributes towards contextualisation. Especially in the first phase, it helps to specify the need for knowledge by identifying which questions the actors involved want to focus on. By mapping the

perspectives of different actors or by setting up constellations in different stages of the research process, the method also contributes towards recursiveness.

Constellation analysis is not restricted to any particular scientific theory or discipline, but is applied primarily for linking different disciplines or perspectives. The basic idea is to bring together various approaches, data sources, and forms of knowledge to create a picture of the constellation at large that can be shared by all disciplines and actors involved. By including natural and technical elements as well as social actors and systems of signs, it draws the attention to the variety of factors which are influencing certain constellations. This “eye-opening” effect can help to search for appropriate multidimensional theoretical approaches instead of concentrating on one dimension only (e.g. the governance perspective only). Depending on the topic which is dealt with, an integrative theoretical approach containing for example elements from innovation research, structuration theory as well as multi governance research is needed to deal with complex life-world problems.

Constellation analysis is a helpful instrument for organising inter- and transdisciplinary processes in sustainability and innovation research which have the same character in developing, emerging and industrial countries. The method could be especially fruitful in questions of technology or policy transfer between highly industrial and developing or emerging countries. By comparing the elements which build up the specific constellations in the two different settings, the challenges of a simple transfer could be made visible and it would be possible to develop an integrative, multilevel transfer strategy.

NOTES

- 1 The constellation analysis has been developed by scientists of the Center of Technology and Society, Technische Universität Berlin and the Nexus Institute, Berlin (Schön et al., 2007). It has been applied in several projects of sustainability and innovation research.
- 2 The research project ‘Innovation Biography of Wind Energy’ was funded by the Volkswagen Foundation from 2004 till 2007 (www.ztg.tu-berlin.de).
- 3 The research project ‘Blocked Transition? Spaces of Thinking and Action for Sustainable Development’ was funded by the German Ministry of Education and Research (BMBF) from 2003-2006 (www.blockierterwandel.de).

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Conceptualizing Sustainable Development as a Global Problem

The Role of Strategic Knowledge

Britta Rennkamp

SUMMARY

Technological innovation and strategic knowledge are crucial to global problem solving. But in the current global governance architecture 'knowledge' is a marginal issue. Classical economic theories do not take into consideration that knowledge is not a public good, free from rival consumption and exclusion. This article briefly outlines the main problems with these approaches and makes an argument for the strategic knowledge that is required for global problem solution. Furthermore it outlines how states can cooperate linking scientific-technological and development cooperation to achieve more sustainable development paths. Evidence derives from bi-and multilateral cooperation experiences from Germany and South Africa.

INTRODUCTION

Multilateral cooperation is in crisis. The Fifteenth session of the Conference of the Parties (COP 15) of the United Nations Climate Change Conference in Copenhagen has shown that the current cooperation platforms do not correspond efficiently to the power dynamics in the international system. Global problems urge governments to cooperate, because no single nation can solve them alone. Financial responsibility is the obvious bottleneck on the way to an international agreement. Less obvious are the politics of knowledge that play a key role in the negotiations of sustainable development and climate change. Economic theory conceptualizes knowledge in a misleading way. This article develops the argument that global problems require multilateral and bilateral scientific and technological cooperation directed towards development. It draws on

a framework that was developed for assessing multilateral cooperation for global problems within an initiative in the Committee for Scientific and Technological Policy (CSTP) in the Organization for Economic Cooperation and Development (OECD) (Fischer and Rennkamp, 2009). Deriving from the general framework on knowledge for global problem solving, this analysis focuses on the South African and German experiences in bilateral and multilateral science and technology cooperation.

GOVERNANCE OF KNOWLEDGE

Neo-classical economic theory conceptualizes knowledge as a public good. Public goods are those goods that are free from exclusion and are unrivalled, no matter by whom or how many people consume them. Taking a closer look shows that this is not valid in the case of knowledge. Knowledge goods can be privatised and exclude people from their consumption. This classical economic paradigm's understanding of knowledge as a public good is a simplification (Kaul, 2008). Some simple examples show the limitations of the concept if applied to knowledge. Physical laws and mathematical theorems are true everywhere in the world. They do not lose their universal validity by being applied and used by people around the world. It is certainly difficult to deliberately control the use of universal knowledge once it has been made accessible to a greater public. Still, in the context of modern technologies, knowledge can be kept secret. Data bases, trade secrets and tacit knowledge developed within the routines of enterprises or research are examples of knowledge being a club good, only accessible to a specific group. Even in the case of patents, where inventors are obliged to reveal the details of their invention in exchange for the right to protect the innovation for a certain period of time, the descriptions of their proceedings are usually kept as vague as possible. Certain configurations of knowledge do create 'rivalry' in consumption of knowledge. For example, in order to make use of specialised knowledge, enterprises need trained people which may be scarce, thus creating competition for human resources (See Figure 1). Consequently, knowledge has to be considered an 'impure public good' (Stiglitz, 1999), and even this applies in very few cases.

Conceptualizing knowledge as a public good is especially problematic if viewed from a global perspective (Fischer and Rennkamp, 2009). Knowledge goods and commons sketched in the table above are unequally distributed in the world. Decades of innovation research have shown that local, regional and national factors matter for the research based creation of a technology and its diffusion (Dosi, 1988; Fagerberg, 1996). Often, the

Figure 1 Types of knowledge goods

		Rivalry	
Exclusion		Low	High
	Low	Public Goods Published scientific knowledge Basic research outcomes	Public Commons Public libraries Human resource, academics
	High	Club Goods Journal subscriptions Trade secrets Restricted data bases	Private Goods Patents, copyrights Corporate R&D staff Classified and unpublished scientific knowledge

processes of technological innovation are place-based affairs embedded in national, regional and local systems of firms, research institutions and public agencies (Freeman, 1987; Lundvall, 1992; Nelson, 1993). Evolutionary theories recognise that technological knowledge is neither equally shared globally among countries, nor within countries among firms. Technologies are understood as tacit and require technological learning and skills to master and create them (Lall, 1992). From an evolutionary perspective firms do not act on the basis of a simple production function. Their technological knowledge varies and in consequence, there is a ‘permanent existence of asymmetries among firms, in terms of their process technologies and quality of output (Dosi, 1988 quoted in Lall, 1992).

Technological capability is still primarily concentrated in the industrialised countries. Developing technological capability also depends among other factors on human resources. Data on the global distribution of human resources show clearly a dominance of the North, where more than two thirds of the world’s researchers live and work (UNESCO, 2009). These researchers produce most of the published knowledge. Although the science bases in many developing countries are growing, the overall distribution is still biased towards the North. Published knowledge may generally be assumed to be a public good, but scientific publications are not necessarily equally accessible and applicable in developing countries. Online access to research papers requires a minimum standard of infrastructure. People may also lack for the ability to search and apply the knowledge. In sum, in many configurations, ‘knowledge’ is not characterised by non-excludability and non-rivalry of consumption and thus not purely ‘public’ in its nature (Fischer and Rennkamp, 2009).

KNOWLEDGE FOR GLOBAL PROBLEM SOLVING

Against the background of serious global problems, knowledge needs to be generated strategically and globally (Fischer and Rennkamp, 2010 (forthcoming)). Five types of scientific knowledge have been put forward for helping to solve the global problem of forging sustainable development paths:

- Firstly, scientific knowledge produced through basic research that contributes to understanding fundamental principles of the respective challenges in all parts of the world. This includes worldwide observation, comparison and monitoring (i.e. climate research, biodiversity observation, medical research).
- Secondly, applied research to generate knowledge for market innovations. Applied research produces the crucial type of knowledge for technological innovation, but the translation of basic research into marketable technology often proves to be very difficult. Establishing linkages between researchers and firms is an important task in both developing and industrialised countries. Firms do not act under conditions of full information in articulating their demand for research. This situation worsens in developing countries where only few firms compete, although innovation and knowledge creating organisations are scarce.
- Thirdly, market knowledge which involves research on the needs, demands and feasibility of innovations for consumers, particularly in the developing world.
- Fourthly, research on the social impact of global challenges. Social scientific research needs to assess the concrete local impacts of global problems to raise awareness in the society. The findings of basic scientific research need to be translated so that societies and policy makers understand their implications. Sound and practical recommendations to policy makers can help to explain the need for collective action. Only if policy makers perceive a problem as such, do they take political action. If they perceive multilateral governmental cooperation as beneficial, cooperation will be likely.
- Fifthly, scientific knowledge for cooperation is necessary to create a substantial basis for (i) assessing the effectiveness of international cooperation mechanisms; and (ii) quantifying the impacts of global problems on societal welfare in financial terms. The financial impacts are not yet transparent. Only if an actor clearly understands the disadvantages that emerge from non-action, will cooperation be legitimate. Today the debates around the global problems are still characterised by high degrees of uncertainty that reduce the possibility of substantial political commitment.

MULTILATERAL AND BILATERAL COOPERATION IN SCIENCE AND TECHNOLOGY FOR SUSTAINABLE DEVELOPMENT

How can multilateral and bilateral cooperation contribute to promote these types of knowledge for sustainable development? So far, there is no coherent multilateral funding scheme to promote strategic knowledge for sustainable development. The current architecture in the global governance of knowledge is deeply fragmented. This fragmentation results from historically shaped institutions, and particularly a vacuum that emerged from inflexible UN institutions. Two examples are the World Intellectual Property Organization (WIPO) and United Nations Educational, Scientific and Cultural Organization (UNESCO), both UN agencies that had originally the mandates for regulating intellectual property (WIPO) and promoting science in developing countries (UNESCO). Both organisations have been sidelined by club-like organisations and regimes. In the case of Intellectual Property Rights (IPR) the Trade Related Aspects of International Property Rights (TRIPS) agreement within the World Trade Organization (WTO) overrules the WIPO. The Organisation of Economic Cooperation and Development (OECD) has become a relevant body for policy advice in the technologically advanced developing countries, rather than UNESCO or the UN Commission of Science and Technology for Development (UNCSTD).

Production and regulation of scientific knowledge is also a cross-cutting issue in other international agencies. The UN Conventions of Biological Diversity and Climate Change (UNCBD, UNFCCC) refer to IPR, as well as the World Health Organization (WHO). Within the UNFCCC framework an Expert Group of Technology Transfer has elaborated manuals and suggestions for national policy makers for technology transfer to adapt and mitigate climate change. The World Summits on sustainable development in Rio and Johannesburg address the knowledge gap at the local and global level through the Agenda 21. Newly created bodies such as the International Renewable Energy Agency (IRENA) also include a component for knowledge creation, the centre for innovation and technology to ensure knowledge production and diffusion.

There is no 'global fund' for strategic scientific knowledge creation in the current international system. Considering the state of international diplomacy around the climate change challenge, it is unlikely that agreement on such common fund would be achieved. Only if all parties are willing to compromise and contribute according to their available financial and human resources, an agreement can be possible. The problem at the moment is that the negotiations are trapped around the overall framework modalities, but the specific issues in IPR and technology transfer have not reached the negotiation tables.

Governments prepare themselves and do foresight and assessment studies to be better informed about impacts and options for the negotiations. For example the South African government has done a Technology Assessment Exercise, started an R&D strategy for climate change and specified the research needs to address global change in a new plan over the past decade.

These national efforts link to multilateral ones. The OECD initiated a multilateral research project on multilateral governance of Science, Technology and Innovation in 2009 to overcome these structural problems and rethink the knowledge cooperation mechanisms against the background of global challenges like climate change, energy security, food security and infectious diseases. This project has the objective to come to a better understanding of how scientific technological cooperation can be organised multilaterally to address global problems. An expert group on technology transfer in the UNFCCC works on advancing development and transfer of technologies under the convention since 2001, although the negotiations are still at its very initial steps to establish an overall global framework of dealing with the climate change challenge. This general discussion on financial modalities and responsibilities is still far away from negotiating the details of technology transfer and IPR.

Bilateral cooperation can contribute to assessing these details between developing and industrialised countries. Science policy dialogues can be useful tools for this purpose, because they allow rethinking positions and cooperation lines in an open environment. Substantial inputs from scientists bring the sciences into the policy domain for discussion for government officials together with representatives from civil society and the private sector. The South African–German Dialogue for Sustainability Sciences is one of these initiatives within the North–South bilateral relationships. Over the course of three years, South African and German officials, scientists and civil society representatives have entered a process of rethinking their cooperation in environment, science, technology and development with the objective to contribute to sustainable development and greening the economies of the cooperating parties.

Strong bilateral relations help to push forward joint positions in the multilateral negotiations, also in the South-South cooperation. The IBSA trilateral cooperation forum between India, Brazil and South Africa is one example. IBSA's initial purpose was to establish a common position between India and Brazil in multilateral organisations like the UN, the WTO and the IMF. Particularly the reform of the UN Security Council aligned both countries in their demand for permanent seats (IBSA, 2006)). South Africa became the third party of the IBSA forum which, in turn, has very strong bilateral relations with India. The forum has expanded its cooperation over the last seven years beyond the initial objectives and now includes

economic, scientific and technological collaborative efforts. The science and technology component is still in an early stage, but if the organisational difficulties can be overcome, valuable research results in areas of infectious diseases and earth observation through the joint satellite programme can be expected.

LINKING BILATERAL SCIENTIFIC AND TECHNOLOGICAL COOPERATION TO DEVELOPMENT

Science, technology and innovation does not rank high on the agenda of policy makers in the field of development cooperation in the industrialised countries. Whereas in the early years of development cooperation, universities were naturally included and supported in setting up engineering departments, these activities stopped for the benefit of other approaches to economic development, that were not based on the idea of creating a knowledge base and education.

Increasing pressure on legitimate and efficient spending of Official Development Aid (ODA) led towards a trend of investing in countable outcomes. The methodologies for impact evaluation of development cooperation intensify these trends. Agencies spend their money in the way that they fit into the indicators that allow them to present high numbers of benefiting individuals and groups to their clients, the ministries, in the home countries. Investment in science, technology and innovation is uncertain. Research and development activities are unpredictable in their outcome and the time they need to generate tangible results.

The so called 'impact chain', that links an activity in the field of development cooperation with the outcome on the ground, for instance, reduction of poverty, is much longer if a donor seeks to strengthen innovation systems in the developing countries rather than in providing houses and medication to the poor. It is easier for donors to count the heads of those who received medical treatment rather than investing in local firms to research and produce vaccines and medication themselves to cure the diseases in the developing world.

Another problem is that policy makers and officials in the industrialised world think of science, technology and development separately. In their cooperation portfolios the connection between science, technology and economic development is poor or sometimes even non-existent. Valuable synergies get lost through thinking in silos along the frontiers of departmental responsibility. In developing countries, the thinking about the value of science, technology and innovation for development is different, obvious and unquestioned. From the developing countries perspective it is

much more important to acquire access to technological knowledge and to ground the component of human resource development into the cooperation mechanisms. The human resource dimension is often forgotten by northern partners who are – in their scientific-technological cooperation – often more interested in flora, fauna and infrastructure in the partner countries. In drafting their calls government agencies should make use of the possibilities to introduce requirements for education and training components and consider these in selecting the beneficiaries of public research grants.

STRENGTHENING SUSTAINABILITY ORIENTED INNOVATION SYSTEMS

Linking the components between environment, S&T and development without losing the focus is the art of strategic knowledge creation. Systemic thinking has influenced the understanding of dynamics and determinants of innovation. Environmental and developmental questions are cross-cutting and systemic in a similar way. To link development and scientific-technological cooperation towards environmental sustainability, 'innovation systems' thinking can be useful to frame both policy and international cooperation. National systems approaches have had the tension to marginalise the international dimensions of the politics of knowledge. Differing from the conventional approach to innovation systems, sustainability oriented innovation systems are open, global and need to generate innovation that contributes to providing global public goods and protecting global environmental commons. The problem with generating environmental innovation is that the innovating firm does not necessarily get all the benefits from investment in innovation in return, and that environmental costs continue to be externalised (Stamm et al., 2009).

As discussed above, knowledge creation is the most important task for sustainable development. Private actors only invest in knowledge creation if it is viable for their corporate interests. This can be market knowledge, consumer knowledge as well as innovative capability to create a new product. Private investment alone does not sustain a knowledge economy. Governmental support is necessary particularly on the supply side of innovation system sustaining universities, research institutions and academic freedom for research independent from the aspects of commercial viability. In developing countries, the human resources still challenge the transition from resource based to more knowledge based production paths. For this reason, all international cooperation lines should ideally contain training and human capital development measures as a cross cutting demand.

Knowledge production for sustainable development is particularly demanding because of its interdisciplinary nature. In the sustainability

sciences these two areas are particularly interlinked, because the nature of the challenge must be well understood to find a solution. Social impact studies and market research are other knowledge components that challenges researchers and firms, because creating this knowledge demands a strong capability of thinking outside the box and outside of the own contexts beyond disciplinary fields and market and non-market orientation of the individual action.

To overcome what Americans call the 'Valley of Death', Europeans call the 'European disease' and South Africans call the 'Innovation Chasm' public and private actors need to work closely together. These concepts refer to the problem of publicly funded research and its problem to survive without the security of public funding to be a commercially viable market innovation. In the area of environmental technologies demand oriented policies try to bridge this gap. Demand is one of the key drivers of innovation (Edler and Georghiou, 2007). Government can introduce regulation for the compulsory use of certain technologies to secure a market for the innovation. A number of industrialised and developing countries, such as Germany and South Africa, have adopted feed-in tariffs to promote renewable energies. In the case of these incentive and regulation schemes, it is crucial to explore the potential adaptations to the technical and socio-economic conditions of the specific countries. Exchange over these policy experiences can be useful for both sides. One of the challenges is to ensure that the created demand can be attended in the sense that not only the technology is feasible but also sufficient number of firms will provide it and have the technicians and experts to install it in even remote areas.

The system approach to innovation and environmental sustainability is useful in two aspects: first, to assess the knowledge that is needed to achieve a transition towards sustainable development, and second, to think about international cooperation that can address either the demand side or the supply side of an innovation system.

International development and S&T cooperation can support these measures on both demand and supply sides. On the demand side, collaborative research efforts can contribute to facilitate access and adoption of environmental technologies and services. Development cooperation can fund and facilitate its diffusion and support the local firms in attending the demand. On the supply side, development and S&T cooperation can strengthen human resources in academia, sciences and engineering by introducing measures that facilitate mutual learning and skills.

Funding of sustainability research is particularly demanding because it needs to produce different kinds of knowledge as mentioned above. This diverse knowledge production requires a long-term orientation of research and a close relationship of basic and theoretical research with applied and

social scientific research. If these different interdisciplinary approaches are linked to solving the same problem, research is more likely to produce practical outcomes. Also important is a strong orientation of the research focus towards individual actors at national, regional and global levels (Hennen and Krings, 1998; Schäfer in this issue).

LINKING COOPERATION LINES: THE GERMAN-SOUTH AFRICAN DIALOGUE FOR SUSTAINABILITY SCIENCE

In the areas of science and technology, environment, development, economic and cultural cooperation ties have been strengthened at the bilateral level. Also in multilateral forums such as the OECD both countries work together closely. The cooperation between South Africa and Germany stands on a solid basis since 1996. Despite the multitude of joint programs, many of them run along independently and leave valuable synergies unexplored.

Among the series of focal areas for development cooperation that the German ministry for economic cooperation and development has defined, none refers explicitly to STI. In the area of education most activities focus on basic education and vocational training. Higher education is funded mainly through scholarship programs organized by the German Academic Exchange service.

This does not imply that development cooperation has not been channelling significant resources that may contribute to building-up of scientific and technological capabilities. But there was no strategic focus placed on this field of activities.

In the last years, there has been a shift in the international development discourse. This shift has led to the approval, in May 2009, of a BMZ position paper 'Knowledge for Development' (BMZ, 2009). This paper includes a commitment of German development cooperation to strengthen knowledge and innovation systems in its partner countries. This basically reflects an increasing awareness, that without strong knowledge and innovation systems, sustained economic growth cannot be achieved; neither can the transition towards ecologically more sustainable growth patterns. A second important framework paper is the 'Strategy for Internationalisation of Science and Research' (BMBF, 2008), initially developed by the Federal Ministry of Education and Research and adopted by the German cabinet in February of 2009. Further initiatives by the German government that aim at international research, science and technology cooperation are framed in the High Tech Strategy (HTS) and the HTS for Climate Change (BMBF, 2006; 2007). These frameworks intend to strengthen research cooperation with developing countries like South Africa to strengthen higher education,

research and innovation systems and link these efforts to foster economic and social development and reduce poverty in the developing world. The South African–German policy dialogue on Sustainability Science is one of several initiatives organised under the framework programme for sustainability research (BMBF, 2005). The ‘Research and Academic Relations initiatives’ (AA, 2009) prominently launched by the foreign office in 2009 has not yet turned into concrete activities in South Africa.

From the South African perspective the National R&D Strategy (DST, 2002) and the 10 year innovation plan (DST, 2008) are the main frameworks that guide international cooperation. Beside multilateral efforts and strong African and other Southern Cooperation lines, Germany remains one of the strategic partners in the north.

The policy dialogues for sustainability sciences have proved to be helpful ways of re-thinking cooperation lines and their objectives. Although being vague in the beginning, the meetings offered the opportunity for government officials to reflect their activities together with their partners beyond the routine of usual commissioned meetings. Policy dialogues included researchers from both social and natural sciences and representatives from civil society helping to spark new ideas and directions for cooperation. Stocktaking exercises and strategic reflection helped to assess the strengths, weaknesses and complementarities of the economies in both countries. These policy dialogues helped to formulate and rethink the interests in the collaboration of both countries against a jointly faced problem to achieve environmental sustainability. These dialogues are useful frameworks for this kind of thinking, because they allow a free space for reflection independently from concrete project and funding negotiations.

As actors from all elements of the innovation system, business, governments, academia and civil society came together, the science policy dialogue offered a way for the sciences to enter the public policy domain. Knowledge from basic and applied sciences, social sciences and business were exchanged and found entry points and new ideas for bilateral cooperation at the intersection of S&T, environment and development.

CONCLUDING REMARKS

In conclusion, the science policy dialogue can be used for strategic knowledge creation on both supply and demand side. That is, to overcome the ‘innovation chasm’ academic research needs to bridge with industrial needs. South Africa has strong innovation support structures that could be extended towards environmental innovation. On the supply side: (i) the parties of the dialogue could consider to introduce a greening component to the innovation support

programmes, e.g. the long-standing THRIP programme and support its extension to other African countries; (ii) create a joint academy with courses for science technology and innovation policy studies, development studies and environmental governance studies to create knowledge for cooperation and policy advice; (iii) encourage visiting researchers to share and exchange knowledge in forms of seminars at the universities and invite students from both countries to participate in collaborative research projects; and (iv) strengthen the linkage between studies and research with projects in the technical cooperation (particularly with partners from the private sectors). On the demand side: (i) development cooperation (technical as well as micro-financial assistance) can help to contribute to diffusion and implementation of environmental technologies, if the government introduces experimental or compulsory use of new technologies, e.g. solar home system; (ii) the political mutual interests can be achieved by increasing the visibility in Africa for both countries, stabilising South African research competences in the region in the field of sustainability, increasing of visibility in environmental technological capability from German researchers using synergies between existing cooperation lines; and (iii) finally, using stronger bilateral relations to come to a better understanding of how global problems can be jointly resolved and bring multilateral negotiations forward.

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Why Radical Innovations Fail

The Case of Technological Change in German Coal-fired Power Plants

Klaus Rennings, Peter Markewitz and Stefan Vögele

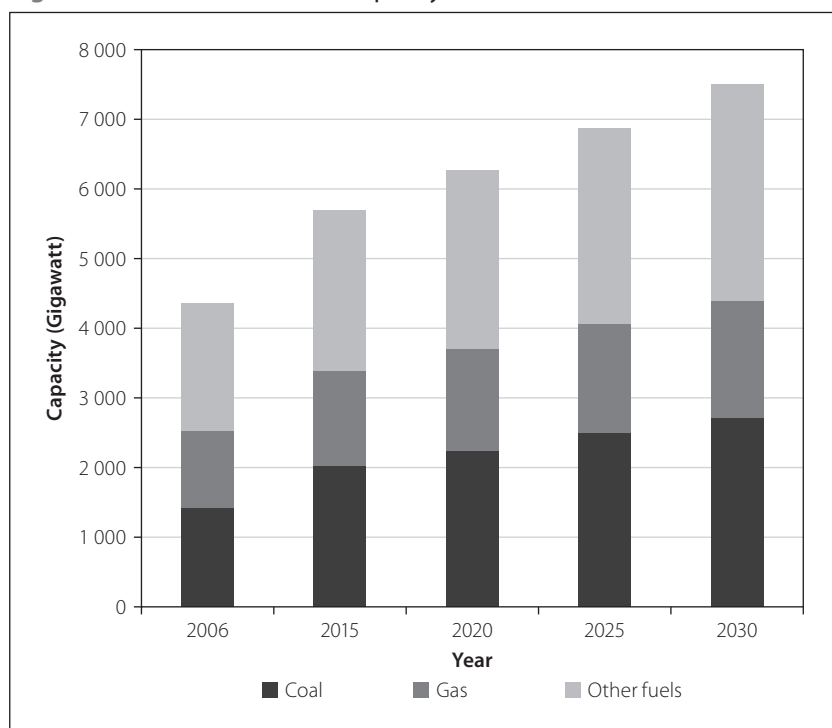
SUMMARY

Radical innovations are frequently called for in order that the transformation of society to a system perceived as sustainable can succeed. The reason given for this is the greater environmental efficiency of these innovations. We review the hypothesis that radical innovations are superior to incremental innovations by taking the case of fossil fuel power plants in Germany. An ex-post analysis of the German R&D portfolio in the past three decades in the field of power plants environmentally shows that technologies which were radical innovations had great difficulties in becoming accepted by possible investors. The future potential of radical innovations in the field of power plant technology is to be regarded as relatively low, especially due to comparatively high cost-pressure, the reluctance of utilities to take risks and the temporal dynamics of technological progress facilitating incremental innovations on the basis of conventional reference technology.

INTRODUCTION

In the discussion on innovations for sustainable development, radical innovations are frequently called for in order that the transformation of society to a system perceived as sustainable can succeed (Vellinga, 2004). The reason given for this is the expectation that these innovations will increase environmental efficiency by a factor of 10, compared to a factor of 2 for incremental innovations (Geels et al., 2004).

The literature, however, provides hardly any empirical evidence in favour of this hypothesis. Supporters of this view admit that such changes need at least one generation in order to become accepted, since they have to pass through several stages. Radical innovations should ideally develop

Figure 1 Predicted increase in capacity worldwide

Source IEA (2008b)

first in small market niches, then diffuse and finally replace existing technologies. In the literature this idea of innovation is described as Transition Management (Geels, 2004).

Against the backdrop of an increasing use of coal-fired power plants and the environmental burden to be expected, the potential and the relevance of radical innovations in this field is of interest to researchers. The International Energy Agency IEA assumes that global electricity and capacity need will increase significantly in the next decade and that fossil fuel power plants will be the central basis of future electricity generation worldwide (IEA, 2008b).

The development of power plant technology in Germany is used as an example in this study to show in an ex-post analysis, to what extent radical innovations have been successful and what were the obstacles with which they were confronted. The relevance of these aspects for future R&D policy is shown by applying the concept to the ongoing discussion of CO₂ capture.

Firstly, the concepts of radical and incremental innovation are described on the basis of theories on innovation in evolutionary economics. Section 3 analyses the development of the R&D portfolio in the last decades. The paper uses the examples of Pressurised Pulverised Coal Combustion and supercritical coal-fired power plants in order to compare the development of

radical and incremental innovations. This part is followed by an evaluation of risks and probabilities of success with regard to technological trajectories of CO₂ capture which are at present globally favoured. Section 5 draws some conclusions.

INCREMENTAL AND RADICAL INNOVATIONS FROM THE PERSPECTIVE OF EVOLUTIONARY ECONOMICS

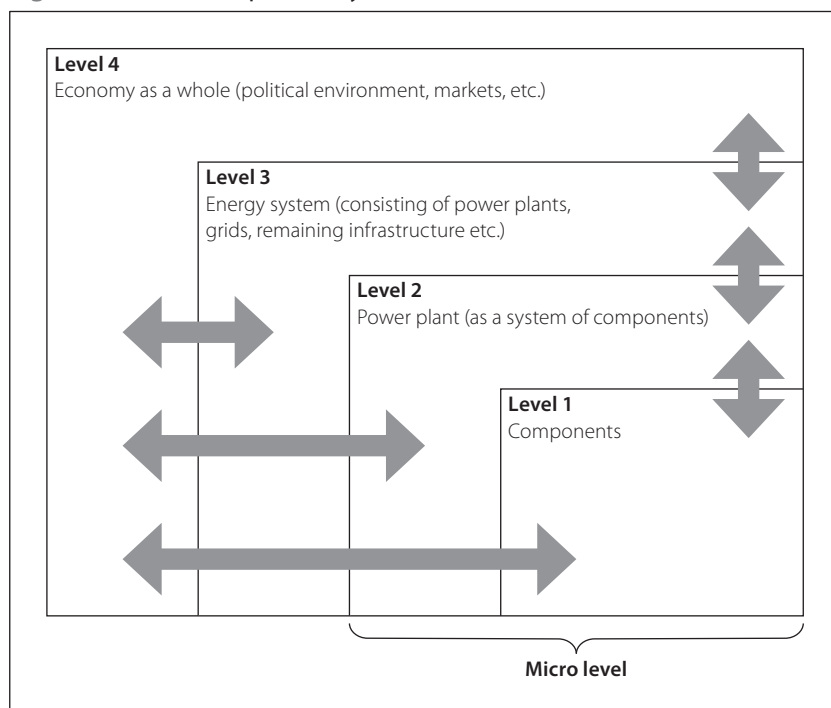
In accordance with the OECD Guidelines for Collecting and Interpreting Technological Innovation Data (OECD, 2005), we distinguish between technical and organisational innovations. Technical innovations are divided into product and process innovations:

- Process innovations occur when a given amount of output (goods, services) can be produced with less input.
- Product innovations require improvements to existing goods (or services) or the development of new goods. Product innovations in machinery in one firm are often process innovations in another firm.
- Organisational innovations include new forms of management, e.g. total quality management.

The following definition of environmental innovation is used in this report (Kemp and Arundel, 1998; Rennings and Zwick, 2002): Environmental innovations consist of new or modified processes, techniques, practices, systems and products to avoid or reduce environmental harms. Environmental innovations may be developed with or without the explicit aim of reducing environmental harm. They may also be motivated by the usual business goals such as profitability or enhancing product quality. Many environmental innovations combine an environmental benefit with a benefit for the firm or user.

This means that, among all innovations, environmental innovations are technological, economic, institutional and/or social changes which result in an improvement in environmental quality (Klemmer et al., 1999). Regarding improvements of coal-fired power plants, it may be controversial if they can be characterised as environmental innovations. However, if the greenhouse gas emissions decrease significantly, or energy efficiency is improved, they can be seen as an environmental innovation.

The extent to which an improvement is made may be classified according to their degree of 'novelty'. Freeman (1992) states that incremental innovations are continuous improvements of existing technological systems (for instance, the optimisation of an exhaust air filter), whereas radical innovations are discontinuous processes (for instance, the introduction of fuel cells).

Figure 2 Levels of ex-post analysis

Before discussing the development of incremental and radical innovations in detail, these concepts must be defined (Garcia and Calantone, 2002). The terms of radical or incremental innovations may be used to refer to a technology at the component level as well as to the entire technological process. Figure 2 shows the different levels of analysis.

As will be demonstrated below, a radical innovation at the component level does not necessarily have to result in a similar innovation at the system level (Level 2). It is, however, a necessary precondition. The (further) development of technology is motivated on the basis of the innovation environment, which is determined by market conditions for operators and providers, energy and environmental policy measures etc. and is represented by Levels 3 and 4 in Figure 2.

The following reflections are mainly concerned with technologies used for the conversion of coal into electricity. Thus the analysis is carried out at a technology-based micro level (Level 2), which, from a technological point of view exhibits a considerably high level of detail, since the technological system to be examined (i. e. the power plant process) is separated into components (Level 1) and analysed (Garcia and Calantone, 2002). Against this background, an innovation is considered radical, if one or more newly developed components change the power plant system, which spurs the development of a new technological trajectory in power plant technology that

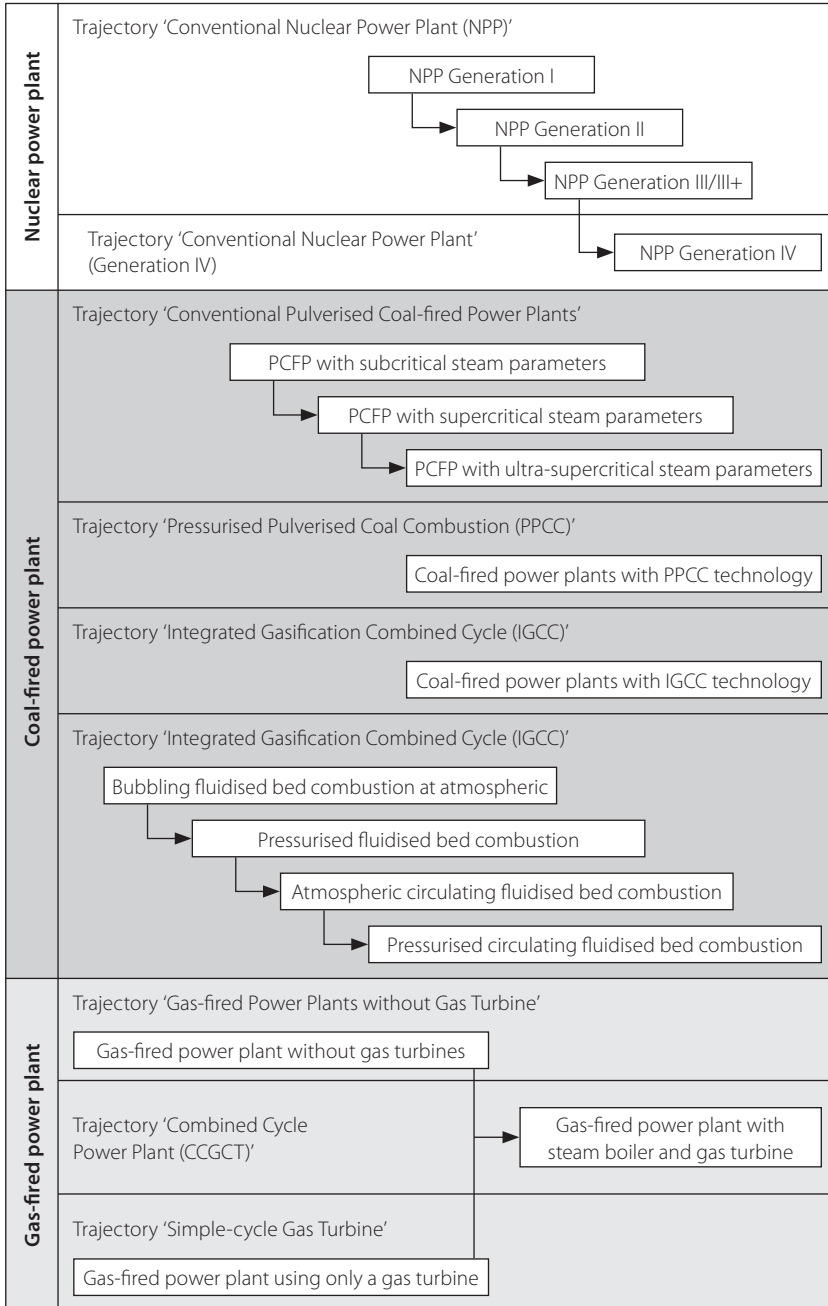
differs considerably from existing technological trajectories and offers significant advantages (for example a leap in efficiency, lower emissions and lower costs.). An example is nuclear power plants, which were developed in the 1950s and 1960s and have been used commercially since the 1970s.

Figure 3 gives an overview of different technological trajectories. In this paper, an incremental change is defined as the further development of a technology while not leaving the chosen technological path. Thus, turbines in the field of power plants have been improved for decades, benefiting from innovations in other areas (for instance, powerful computers allowing for three-dimensional simulation) and thus finally creating an increase in efficiency. Another example is the development of materials that made it possible to increase steam parameters and thus contributed to an increase in efficiency of fossil fuel power plants.

Approaches in evolutionary economics accept that development paths are historically conditioned, which enables them to consider coincidences or path-dependence when analysing technological change. They are more focused on exploring transition and learning processes than balances. Their central elements in terms of methodology are ex-post analyses in the form of case studies; the success of a certain technological trajectory is considered unpredictable. Since actors have incomplete information, technological development is inherently uncertain. These approaches are consequently sceptical about generalisable conclusions or predictions and instead generally tend to emphasise the context-dependence of innovation processes (Rennings, 2000).

It is important to note that the terminology of variation and selection is, firstly, focused on technological innovations and, secondly, does not take into account complex feedback processes between variation and the selective environment. In the latter case one can speak about a process of co-evolution (Rennings, 2000). Using the terminology of variation and selection, selective pressure of the environment may result in the establishment of a certain technological trajectory as the dominant technological paradigm. Economies of scale and scope, learning curves, positive cost-benefit ratios and compatibility with existing life styles, infrastructure and institutions create path-dependences and technological paradigms (Dosi, 1988), i. e. lock-in effects which impede the development of alternative options. The combustion engine or semiconductors are examples of such technological paradigms.

In order that new technologies may be developed alongside such established paradigms, resistance has to be overcome. Policies pursuing this goal aim at opening ('unlocking') a socio-technical system (Faber and Frenken, 2008). Kemp (1997) mentions several determinants and success factors of technological change: new scientific findings (providing new technological opportunities), serious technological bottlenecks (e.g. the limits of additional

Figure 3 Key technological trajectories in power plant technology

emission reductions based on additive technology, high costs of improving a technological trajectory, such as cost-intensive reductions in CO₂ emissions, changes in demand, scarcity of resources or industrial conflicts), entrepreneurial activities and institutional support for radical new technologies.

Key success factors for a change in technology are the early establishment of market niches and the use of existing knowledge and technology, i.e. a certain compatibility with existing know-how, experiential knowledge and existing infrastructure. On the basis of these success factors, (Kemp, 2007; Kemp and Rotmanns, 2005) Kemp suggests supporting a change for more eco-friendly technologies through a policy of transition management. In the Netherlands, the approach of transition management has been met with noticeable response from policy-makers in recent years. This strategy is based on the attempt to induce system innovations facilitating sustainable development. The goals of such innovations are technical, socio-cultural, regulatory and economic systems which meet certain social requirements, such as the need for energy, housing, mobility or food.

System innovations are fundamentally different technologies for meeting these needs; they also necessitate addressing the economic, legal and socio-cultural conditions which determine the relevant technology (Rennings et al., 2004). Examples of system innovations are the transitions from sailing ships to steamships or from coal-based to gas-based energy supply.

System innovations, and thus the approach of transition management, are long-term transitions (at least 25 years). Based on the strong commitment of all participants to long-term goals they are to be achieved and implemented in concrete projects. The creation of protected spaces for up-and-coming, but not yet fully developed technologies is considered a promising strategy. This implies, for instance, the creation of temporary pilot markets, protected by funding programmes, subsidies or other regulatory measures.

According to Berkhout, (Berkhout et al., 2004) such transitions from one technological regime to the next are not imperative. They list a range of other options, including, for instance, a re-orientation of the existing technological trajectories. Such a re-orientation implies that the existing system reacts to the selective pressure of its environment by improving innovations on the existing technological path (Berkhout, 2005). Continuous improvements of an 'old' technology before or after the introduction of a 'new' technology, not least due to the new competitive situation, are familiar phenomena in innovation studies (Rosenberg 1972), and also for environmental innovations (Lutz et al., 2005). Before a lock in situation can be overcome, a window of opportunity should be open (Sartorius and Zundel, 2005).

INCREMENTAL AND RADICAL INNOVATIONS IN POWER PLANT TECHNOLOGY IN GERMANY

In the following, an ex-post analysis is used to examine the German R&D portfolio for the field of large-scale power generation with a focus on the

development of radical and incremental innovations. A particular focus is on research activities that were publicly funded during the last decades. Concomitantly, the R&D portfolio examined represents a part of the industrial R&D portfolio, since a wide range of projects were cooperatively funded by public sponsors and the industry. Unlike purely industrial research, the public portfolio contains a large number of technologies and technological trajectories, which imply a much greater development risk. Thus the participation of the industry may also be interpreted in terms of a distribution of risks.

In a first step, the course of development is scrutinised and an analysis investigates incremental or radical innovations which received particular attention from research and development and examines whether and/or to what extent they established themselves in the market. The example of Pressurised Pulverised Coal Combustion (PPCC), which was considered a promising technology for the conversion of coal into electricity due to its large potential to increase efficiency, demonstrates that in spite of assumed advantages, radical innovations are not necessarily successful.

THE RESEARCH AND DEVELOPMENT (R&D) PORTFOLIO

Table 1 depicts the development of the R&D portfolio in the field of power plant technology in Germany over several decades. It differentiates between R&D portfolio, power plant construction/demonstration and pilot plants and existing power plants. When interpreting this table, it should be noted that, for political reasons, research focused on different issues in each decade: in the 1970s, oil crises caused the research portfolio to focus on resource conservation and a change in energy sources, whereas in the 1980s environmental protection and in the 1990s climate protection was the guiding theme. Until 1998, the electricity market was a monopolised market. In this context, a wide range of pilot and demonstration plants were realised. Since 1998, however, a clear decrease in demonstration plants and a trend towards smaller and less cost-intensive technologies can be observed. The reasons are obvious: in a monopolised market, risks could simply be passed on to the end customer, whereas this is not possible in the now deregulated market.

To establish itself successfully, a technology passes through both the phases 'R&D portfolio' and 'power plant construction/demonstration and pilot plants' and finally becomes a significant element of existing power plants. An example of particularly successful R&D activities is the work done in the area of desulphurisation and denitrification, which became a major basis for implementing the German Großfeuerungsanlagenverordnung (GFAVO, Order on Large Combustion Plants): within one decade they passed through the R&D phase and the demonstration phase, so that all existing German power plants could be provided with large-scale systems by the early 1980s.

Another successful example of the establishment of a radical system-level innovation in the market is the construction of nuclear power plants (pressurised-water and boiling-water reactors).

In the field of fossil fuel power plants, many technologies could not establish themselves beyond the phase of demonstration and pilot plants. It must be noted that no radical innovation has succeeded at the system level during the last three decades. This applies, for instance, to technologies for the conversion of coal into electricity on the basis of coal gasification, which did not succeed on an international scale either. Thus no fundamental change of path (change in technological trajectory) could be observed in the field of fossil fuel power systems during the last decades, despite the existence of new power plant models (e.g. Integrated Gasification Combined Cycles or Pressurised Pulverised Coal Combustion), which constitute radical innovations and stand out due to their higher degree of efficiency or eco-friendliness compared to established technologies.

At the component-level, however, a few changes in technological trajectories could be observed. One example in the field of coal-fired power plants is the transition from slag-tap firing to pulverised fuel firing with dry ash removal, which was triggered by the introduction of the German GFAVO (Order on Large Combustion Plants) prescribing strict limit values for nitrogen oxide. Another reaction to the prescription of emission limits is the development of scrubbing technologies to remove sulphur and nitrogen oxide from flue gases, which did not exist before and thus must be considered a radical innovation at the component level. The component-level changes mentioned did, however, not fundamentally change the actual power plant process as a whole and thus cannot be considered radical innovations at the system level 'power plant' (Level 2).

Other procedures, which are de facto alternatives to the above-mentioned SO_2 and NO_x scrubbing technologies, such as fluidised-bed combustion systems, could not establish themselves as expected, since their potential use entails also new restrictions (e.g. lower performance) and a dramatic change in the actual power plant process (e.g. replacement or fundamental modification of the steam generator). Fluidised-bed combustion systems offer the advantage of being compatible with a broad range of fuels and therefore serve a niche market today. Apart from few exceptions, the further development of fossil fuel power plant technology has had an incremental character. Thus, the increase in efficiency of conventional power plant technology by way of increasing the steam parameters pressure and temperature played a decisive role in all decades and independently of the demands and conditions created by energy- and environmental policy. Due to this development a combination of established gas and steam cycles (CCGT plants) became possible which significantly increased degrees of efficiency.

In the following, Pressurised Pulverised Coal Combustion is used as an example in order to examine why technologies that are considered radical innovations and are assumed to offer considerable advantages, compared to conventional technologies could nevertheless not establish themselves.

PRESSURISED PULVERISED COAL COMBUSTION (PPCC) AS A RADICAL INNOVATION

An increase in efficiency is often the main motivation for conducting R&D projects. Based on the state of the art at the beginning of an R&D project, the efficiency potentials indicated – in comparison to established competitive technology – are generally seen from a medium- or long-term perspective. In contrast to conventional coal-fired power plants, Pressurised Pulverised Coal Combustion is a combined process, in which a gas turbine receives direct pressure using pressurised flue gas from a coal firing. Unlike conventional processes, PPCC requires hot-gas filtration at highest temperatures (approx. 1400°C), which at the beginning of R&D activities implied venturing into uncharted territory. In addition, the boiler design had to be modified for operation under pressure. After 1985, only dry pulverised fuel firing was used in power plants due to emission limits. Realising the PPCC process would have required slag-tap firing, thus implying a trend reversal. In summary, the new model, requiring the development of completely new components (such as hot-gas cleaning) and the modification of established components (such as the steam generator), qualified the PPCC process as a radical innovation in the field of power plants.

Research and development activities were started in the late 1980s in the context of a cooperative research project, which included many private companies (operators and constructors). In 2003, however, R&D activities were terminated and the promising power plant process, which accounted for development cost of approximately €90m, was never realised.

Table 2 contains information on the efficiency of state-of-the-art technology in the late 1980s as well as efficiency projections for several power plant technologies at that time. The significant advantages of Pressurised Pulverised Coal Combustion are clearly visible. Compared to conventional power plant technology, PPCC promised an increase in efficiency by 5 to 10 percentage points, which was the actual motivation for the industry and public sponsors to participate in the project. A comparison with today's state of the art, however, paints a different picture. It becomes clear that the potential of conventional power plant technology to increase its efficiency had been greatly underestimated. The assumed efficiency advantage of PPCC thus diminished considerably over time. Experts had not expected the remarkable progress that took place in material research and in computer simulation, which particularly benefitted conventional technology. A

comparison of today's efficiency projections, which are listed in Table 2, shows that PPCC has now only an efficiency advantage of 2 percentage points. Since conventional and proven technology achieves similar degrees of efficiency and high technological availability is ensured, work in the field of PPCC was terminated after 15 years of continuous R&D activities. The core problem of PPCC, high temperature ash removal, was solved at the stage of experimental plants. The next step would have been constructing a pilot plant and afterwards a demonstration plant. This was, however, not supported by public sponsors, neither by the industry, which sponsored all project phases but whose participation decreased throughout the project.

A similar picture may be painted in the case of power plants based on Integrated Gasification Combined Cycle (IGCC). Several of such large-scale plants currently operate, for example in the Netherlands (Buggenum), Spain (Puertollano) and in the USA. Since the technological availability necessary to be competitive cannot be provided with those plants, their operation is subject to high risk. This risk has a direct impact on profitability, thus global power plant operators do not include them in their plant portfolio. The few plants that were built currently serve niche markets (such as refineries).

Table 2 Net efficiency (state of the art and projections) at the beginning and at the end of R&D activities in the field of PPCC for different trajectories of power plant technology

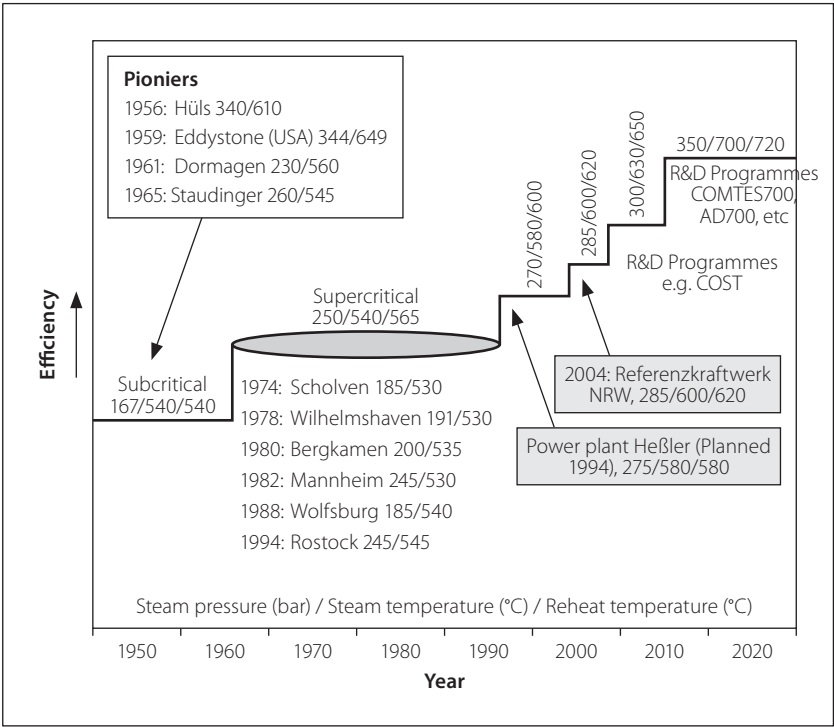
	1989		2003	
	State of the Art	Projections 1989 – 2020	State of the art ²	Projections ^{2,4} 2003 – 2020
CCGT (natural gas)	52% ⁽¹⁾	54% ⁽⁷⁾⁽⁸⁾	58%	65%
Conventional coal-fired power plants (brown coal)	36% ⁽¹⁾	n.s.	43.5%	50%
Conventional coal-fired power plants (hard coal)	40% ⁽¹⁾	44% ⁽⁶⁾	46.9%	53%
IGCC (brown coal)	–	49% ^(1,3)	45–48%	54–57%
IGCC (hard coal)	–	45–47% ^(1,3)		
PFBC	–	44% ^(1,3)	–	53–55% ⁽⁵⁾
PPCC	–	49–53% ^(1,3)	–	53–55%
Note: (1) Pruscek et al., 1990; (2) COORETEC, 2003; (3) Turbine inlet temperature: 1150°C; (4) Specifications for 2020; (5) 'Second' generation; (6) Lezuo et al., 1989; (7) Martin, 1988; (8) Turbine inlet temperature: 1300°C				
Abbreviations: CCGT: Combined Cycle Gas Turbine, IGCC: Integrated Gasification Combined Cycle, PFBC: Pressurised Fluidised-Bed Combustion, PPCC: Pressurised Pulverised Coal Combustion				

SUPERCritical COAL-FIRED POWER PLANTS AS AN INCREMENTAL INNOVATION

The results outlined above also hold true for incremental change in technology, such as the transition to supercritical steam parameters. The development towards high steam temperatures and steam pressures directly resulted in improved efficiency and took many decades, as shown in Figure 4.

The individual plants shown in the figure represent milestones in the development of steam parameters. Supercritical steam parameters had been realised in some power plants ('pioneers') since the late 1950s. They were, however, marketable only 30–40 years later. On the one hand, this was due to the use of expensive austenitic steels. On the other hand, the materials used in the pioneer plants were then found to have inadequate thermal properties, which significantly decreased technological availability. Only with increasing progress in the field of material research was it possible to develop materials which met thermal requirements and were more cost-efficient. While for hard-coal-fired power plants the transition to supercritical steam parameters took place in the 1980s, for lignite-fired power plants it was induced in the 1990s. Consequently, all newly constructed lignite-fired power plants in Germany operate with supercritical steam

Figure 4 Development of steam parameters in hard-coal-fired power plants



Source: ????

parameters, which, along with other methods, increase net efficiency to as much as 42 per cent. Currently, intensive research is conducted in order to further increase live-steam parameters (350 bar, 700°C). Ultra-supercritical hard-coal-fired power plants are predicted to achieve an efficiency of more than 50 per cent (see Table 2). The efficiency advantage of competitive new trajectories of power plant technology thus continuously decreases.

Apart from an increase in efficiency by increasing temperature and pressure, other improvements must be noted. For example, the design of gas and steam turbines and their components was optimised using three-dimensional simulations, which were made possible by the introduction of more powerful computers. The same holds true for the design of other components (e.g. cooling tower) and the optimisation of the whole power plant process. These individual developments accumulated to a considerable increase in efficiency of established trajectories of power plant technology (CORETEC, 2003).

CARBON DIOXIDE CAPTURE IN POWER PLANTS: RADICAL OR INCREMENTAL?

In the context of a reduction in CO₂ emissions from fossil fuel power plants, the use of CO₂ capture and storage (CCS) technologies is increasingly debated (IEA, 2008a; IPCC, 2005). However, in the economic debate, CCS is often seen as a single technology and the introduction only depends on the level of carbon prices (Otto and Reilly, 2008). CO₂ abatement costs are estimated between 35 and 50 Euro for 2020 (SRU – Sachverständigenrat für Umweltfragen, 2008). For many experts, CCS may only be seen as an incremental innovation since it is based on fossil fuels. In fact, there are considerable differences between the technologies in question. Three technological processes are currently favoured: in post-combustion, CO₂ is removed from flue gases by means of solvents and thus captured after combustion. In oxy-fuel combustion, coal is not burnt using the ambient air but with pure oxygen and recycled flue gas, consisting mainly of CO₂ and water vapour. The flue gas produced consists mainly of CO₂. In the third process, pre-combustion, carbon is removed from the energy carrier prior to the actual combustion process in the power plant. This procedure is used in Integrated Gasification Combined Cycle (IGCC) power plants. The three technological trajectories differ in their technological proximity to existing power plant models, in their marketability, in the risks associated with their use and their expected financial advantages in comparison with known technologies. In principle, power plants using CO₂ capture combine a trajectory of power plant technology with a capture procedure. Thus the following comparative assessment, as shown in Table 3, differentiates

between the actual basic process and the capture procedure. Subsequently, the overall process is assessed.

A risk assessment for CO₂ transport and storage is not required in the following analysis, since it has no influence on the comparison of technological trajectories.

A comparison of basic processes makes it clear that post-combustion as well as oxy-fuel combustion are added to power plant processes which dominate the global market for power plant technology. They confirm the impression that this kind of CCS technology is only an incremental improvement of coal power plants. The IGCC power plant, on the other hand, is considered a radical innovation, which is, in principle, commercially available, but is hardly used in power generation. Large-scale use requires further optimisation and improvement of components (gasifier, gas turbine) to achieve the necessary degree of availability.

When combining basic processes with capture processes, a possible modification of the basic power plant process may be considered. With post-combustion and pre-combustion, however, modifying the basic process is generally not necessary. From a technological as well as an economic point of view, the steam generator and the firing are the decisive components in a power plant process. In oxy-fuel combustion, they need to be newly dimensioned and designed, thus considerably increasing the technological risk compared to both above-mentioned processes.

Components of different CCS technologies are commercially available and are currently used in chemical industry. The air separation unit required for oxy-fuel combustion, for instance, is state of the art. CO₂ scrubbing, which is based on the principle of chemical and physical absorption by means of solvents, is currently used in chemical industry (e.g. in ammonia production or refineries). Due to the high volume flow rates of a power plant, the technological components currently available need to be scaled up in all processes. The individual CCS processes do not differ in their technological risk.

Using CO₂ capture processes results in substantial efficiency losses for all technological trajectories, caused by the additional use of energy for air separation (oxy-fuel combustion) and by the regeneration of the 'rich' solvent containing the CO₂ (post-combustion, pre-combustion). From today's perspective, efficiency losses are largest in the overall process of post-combustion, while they are more moderate in other processes. The development of improved solvents, however, is expected to unleash remarkable efficiency potentials. The highest efficiency potential is found in the overall process of pre-combustion, since it is particularly suited to CO₂ scrubbing for reasons of technology and, moreover, its basic process is regarded as having high efficiency potential.

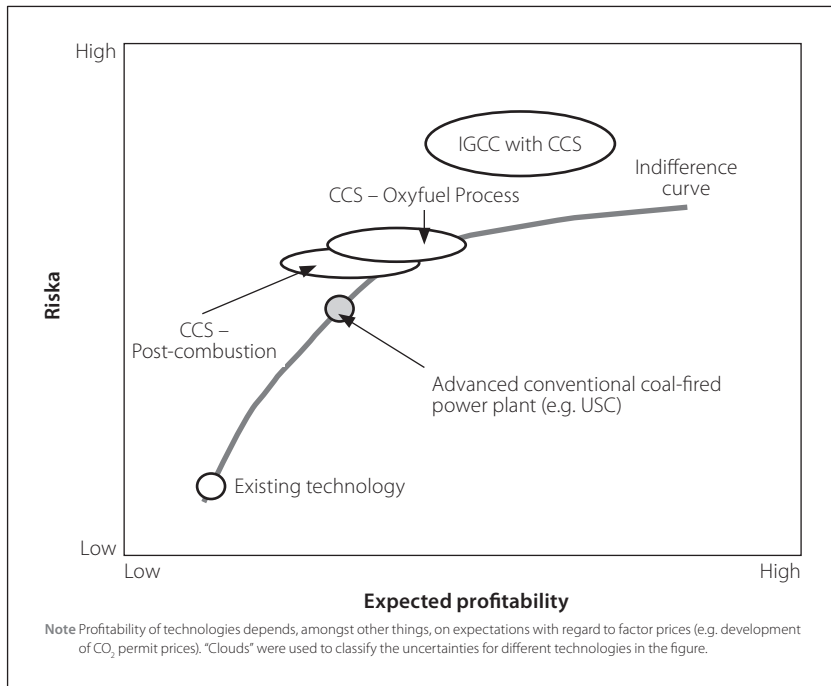
The individual technological trajectories exhibit several additional characteristics which may significantly influence their use. Post-combustion,

for instance, is the only process suitable for retrofitting (the addition of new technology or features to existing plants). Against the backdrop of increasing efforts to mitigate greenhouse gas emissions, this characteristic may be considered an advantage. Oxy-fuel combustion is regarded as more eco-friendly, since no chemical additives are required. In pre-combustion, the hydrogen used for electricity generation may also be used for other purposes. This process may thus be used very flexibly and possibly pave the way for a hydrogen economy.

All technological trajectories are associated with significantly higher investments, exceeding those of the basic process by at least 50 per cent (ignoring CO₂ transport and storage). When comparing the necessary investments of the basic processes, those of steam power plants are, from today's perspective, clearly higher than those of an IGCC power plant.

Since CCS technologies do not differ in risk, the evaluation of the overall process is mainly determined by the basic process. Based on the results of the ex-post analysis, the risk of pre-combustion is considered the highest, as this process is added to a basic process constituting a radical innovation. Due to the modification of the steam generator, oxy-fuel combustion is thus considered to pose a somewhat higher risk than post-combustion, which has closest technological proximity to established power plant processes.

Figure 5 The risk/profitability ratio for CCS technologies



Source: ????

Since CCS technologies do not differ in risk, the evaluation of the overall process is mainly determined by the basic process. Based on the results of the ex-post analysis, the risk of pre-combustion is considered the highest, as this process is added to a basic process constituting a radical innovation. Due to the modification of the steam generator, oxy-fuel combustion is thus considered to pose a somewhat higher risk than post-combustion, which has closest technological proximity to established power plant processes.

Figure 5 shows a comparison of different CCS technologies with regard to the associated risks and their expected advantages. Both post-combustion and oxy-fuel combustion pose relatively low risks to investors. The use of IGCC in combination with CCS, on the other hand, may involve more difficulties as regards continuous commercial operation. Yet such technologies may prove more profitable than others.

Since investors in the field of power plants are currently highly risk-averse, it must be anticipated that radical technologies are associated with higher risks than an incremental improvement. Thus their large-scale establishment is possible only if existing risks are significantly reduced or expected profitability can be significantly increased.

CONCLUSIONS

In the case of power plant technology, one observes a classical lock-in situation – not to be equated, however, with the well-known case of the typewriter keyboard (the QWERTY example), where the less convenient system was successful in technological evolution due to advantages of standardisation (David, 1985). Pressurised Pulverised Coal Combustion, did indeed perform less well in a dynamic comparison and did thus rightly not establish itself. Whereas it might have come out ahead in a comparison with the original reference technology, technological progress of the ‘old’ technology was significantly underestimated.

The classical lock-in situation is supported by the deregulation of the electricity market. Many hard-coal-fired power plants built in the 1970s and 1980s have to be regarded as unique and tailored to the specific needs of their operators. Increasing global demand for power plants, but also deregulation of the electricity market has changed the general conditions for European power plant constructors. The main goal is global competitiveness (Level 4).

This will probably not make enterprises more willing to take risks, since they are now exposed to serious competition which does not forgive wrong decisions. In a competitive market, more importance is attached to the criterion of profitability.

In this context, cooperative research – cooperation with competitors – becomes increasingly relevant. It ensures that development risks are pooled and may thus be understood as risk sharing in the broader sense. Furthermore, participation in cooperative research projects gives access to information, which might eventually constitute a competitive advantage. One example is the research project COMTES700 (development of ultra-supercritical power plants), in which besides research institutes a number of national and international utilities (e.g. E.ON, EdF etc.) and power plant constructors take part (Jäger, 2005).

Power plant standardisation, elimination of redundancies and reduced construction time further contributed to reductions in investment costs and are expected to do so in the future. Power plant design strives to meet the needs of global (in particular, Asian) consumers. The call for increased plant availability plays a decisive role in this: it has to be guaranteed by constructors, who thus face high financial risks and are consequently less willing to take the risk of ‘experimenting’ with new technology. New or improved technologies have to be presented and tested in the country of manufacture before being exported. A successful example is the introduction of supercritical hard-coal-fired power plants in China. Whereas Europe had completely switched to supercritical power plants in the 1990s, in China only plants with subcritical steam parameters were constructed. Only since 2000, with a time lag of roughly 10 years, supercritical power plants have been constructed on a large-scale basis. It can be expected that CCS technology will be diffused to China with similar delays. However, due to the political pressures on emerging countries like China, and the abundance of coal reserves, CCS technologies are likely to be used in these countries in the long run.

An ex-post analysis shows that – in contrast to incremental innovations – radical innovations mostly did not succeed, despite their evident advantages (more eco-friendly, more efficient). This holds particularly true in the field of power plant systems. When focusing on fossil fuel power plant technology, several radical component-level innovations were made and diffused into the market during the last three decades. Yet no radical innovations were made at the system level in this field, which indicates its strong path-dependence. The risk that new technological trajectories cannot establish themselves is particularly high in the case of newly developed components or a trend reversal at the component level which eventually constitute a radical innovation in the power plant system. In the field of fossil fuel power plant technology, an innovation is more likely to succeed the more it follows established technological trajectories.

The results gained in the ex-post analysis also allow for an assessment of power plant technologies for future use, as has been shown using the

example of carbon capture technologies. The results are inherently uncertain, since it is not possible to precisely predict the general conditions prevailing when using the technology. Highest priority must be given to path-dependence, since it has been observed in the field of coal-fired power plants for decades and carries more weight than other criteria.

From a social perspective, a reasonable strategy would be to further develop all three CCS technologies. While the incremental post combustion technology has the advantage that it can be used for retrofitting (which may be most urgent e.g. for existing German power plants), the radical pre combustion technology is more efficient but the window of opportunity (at least in Germany) may be already closed when the technology is in a mature phase of development. Thus a reasonable R&D portfolio should include both post and pre combustion technologies, at least for international appliances. If R&D on CCS is left to energy suppliers, it can be expected that only the incremental technology is realised and that the radical technology will not be further developed.

The analyses conducted also indicate that the dynamics of technological progress and thus the development of incremental innovations have often been underestimated. Advantages ascribed to a radical innovation in comparison to incremental development have changed over time due to research and development activities. Consequently, technologies in the R&D phase should be evaluated gradually, in time intervals, since every indication of, for instance, efficiency and cost potential has to be regarded as a mere snapshot.

In other words: new technologies have to compete with 'old' technologies. While the latter are not to be considered static – it has to be taken into account that the old technology is, in the light of its competition with the new technology, continually further developed. This experience gained in innovation research was confirmed using the example of power plant technology. Thus, sceptical views regarding a transition from one technological regime to the next have been confirmed in our paper. There is a range of other options, one example is a possible re-orientation of existing technological trajectories (of conventional coal-fired power plants in this case). Such a re-orientation implies that the existing system reacts to the selective pressure of its environment by incrementally developing innovations on the existing technological path (in this case, in the form of supercritical coal-fired power plants). While planning any transition, such development paths should also be taken into account.

The development of new technologies in the field of power plants is essentially motivated by an envisaged increase in efficiency. This holds true independently of the conditions created by energy and environmental policy. Yet the ex-post analysis shows that this criterion is generally

overestimated, whereas other characteristics (e.g. availability) which significantly influence economical power plant operation and thus profitability do not receive sufficient attention.

Deregulation of the electricity market constitutes a fundamental change in environment. It is evident that more pilot and demonstration plants were constructed before deregulation than afterwards, since in a monopolised market, potential cost of failure could more easily be passed on to the end customer. Consequently, there will probably be less willingness in the future to take the risk of developing and implementing a radical innovation at the system level.

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In Search of Green Knowledge

A Cognitive Approach to Sustainable Development

Andrew Jamison

Looking for an expression that could capture the change that has occurred in the last century and a half in the relation between science and society, I can find no better way than to say that we have shifted from Science to Research. Science is certainty; Research is uncertainty. Science is supposed to be cold, straight and detached; Research is warm, involving and risky. Science puts an end to the vagaries of human disputes; Research fuels controversies by more controversies. Science produces objectivity by escaping as much as possible from the shackles of ideology, passions and emotions; Research feeds on all of those as so many handles to render familiar new objects of enquiry.

– *Bruno Latour*

IT ALL STARTED WITH STEAM CARS

There was a brief moment in the early spring of 1968 when it seemed not only possible but actually quite likely that the war in Vietnam would soon come to an end – and largely because of the mobilisation of youthful idealism. After Eugene McCarthy, the poetic senator from Minnesota with his band of student supporters, including yours truly, had nearly beaten the incumbent president in the New Hampshire primary in February, President Lyndon Johnson declared that he would not seek, nor would he accept his party's nomination to run for re-election in the upcoming fall election. Soon thereafter, Robert Kennedy had joined the race, taking on McCarthy in a series of primaries that began in Indiana in early April and would conclude with the final showdown in California in June, when Kennedy would win – but then be murdered, leading to the chaos in the streets of Chicago (This writer was also there), the election of Nixon in November and the prolongation of the war for seven more years – which drove me to Sweden, where I have lived ever since.

It was in that brief hopeful moment so many years ago that I began my lifelong search for green knowledge. I had gone off to Indiana to campaign for McCarthy against Kennedy, and I can still remember that heady feeling of empowerment from those days in New Hampshire when I had taken part in something truly significant. We had brought down Johnson, and now we were going to stop the war. Whatever else got destroyed that year – in me as in so many others – I have always retained a healthy respect for the power of idealism – and collective action – to change things, or at least to shake things up. I felt it, even though the feeling was soon gone.

I was 19, a particularly impressionable age to be sure, in my sophomore year at Harvard and a budding journalist, serving as science editor of the *Crimson*, the student newspaper. In my studies, I had just begun an undergraduate concentration in history and science, taking courses in both of what C.P. Snow had termed the two cultures – the literary and the scientific – with ‘tutorials’ in history of science to try and reveal the hidden connections between them. I had gone to Harvard to become a scientist – my Dad was an industrial chemist and maths had been my favourite subject in high school. We were taught that ours was the age of science (on TV there was the jovial ‘Mr Wizard’ in his lab coat and his infinite wisdom, showing us between commercials all of the wonderful things that science could do: I loved it). However when I got to Harvard I found it hard to deal with the involvement of scientists in the war effort, and the way in which the military seemed to dominate the sciences. I wandered into the woolly world of interdisciplinarity where I have remained ever since.

It must have been shortly after my return from Indiana that I received a phone call from Bryce Nelson, who worked for the news and comment section of *Science* magazine in Washington. He asked if I would like to spend the summer serving as a student intern, and without really knowing what I was getting into – namely signing up for life in the not yet existing environmental movement – I said sure, be happy to, sounds like a wonderful opportunity. And so it was that in June – between the murders of Martin Luther King and Robert Kennedy, when the mood of the country was beginning to change considerably – I arrived in Washington to begin my internship.

I should say that I had been aware of the environmental debate that had been going on for several years by then, but like many, if not most student ‘activists’ at the time, I had tended to disregard it. Compared to the destruction in Vietnam, the problems that were discussed in the environmental debate seemed to be of relatively minor importance. Even worse, the environmental debaters seemed to be challenging the very idea of progress and science-based innovation that was so central to modern civilisation – and to my own belief system. Many of the environmental debaters seemed

to be politically naïve, even downright reactionary in their concern with population growth and protecting nature when there was a dreadful war to stop. How dare they complain of dead birds when people were getting killed every day in a far off land by our own government?

It was thus with some trepidation that I took on my first assignment for Science. A Senate committee had recently held hearings on alternatives to the internal combustion engine, and I was asked to do a story. I remember talking to one of the staff people at the Senate office building and wondering how he could get so excited about automotive air pollution. But gradually, as I worked my way through the hearings and the background reports that had been prepared, I found myself getting intrigued. For I soon realised that there was a perfectly good alternative to the internal combustion engine that didn't pollute the air, namely, the steam-powered automobile, and the only reason that there weren't such things available was the opposition of the auto companies.

Steam cars had been the main kind of car back at the turn of the century, and it had not been due to any overriding technical drawbacks that they had disappeared from the 'market'. Apparently, they had never been inferior to gas cars on purely technical grounds (if such grounds actually ever exist); rather, as the automotive industry had developed, by exploiting the methods of mass production initiated by Henry Ford, steam powered automobiles had become outmoded – antiquated symbols of a bygone age. It was their cultural meaning that had buried them, not their technical capacities. Over the years, there had been a few attempts to revive them, but they had never been able to shake off that stigma of premodernity, even though it was known fairly early on (I later found an article in *Scientific American* from the 1920s pointing to the fact) that they did not pollute the air the way gas cars did.

In the late 1960s, when it had become ever more obvious that automotive air pollution was dangerous to the natural environment and to human health, steam cars were thus staging something of a comeback. A handful of idealistic automotive mechanics and professional engineers – and, not least, officials in California who were trying to do something about the smog that was afflicting Los Angeles – were paying them some attention, and the Senate was about to take the unusual step of passing a bill to support funding for some of the development work.

When I returned to college in the fall, I received a letter from Indiana University Press, questioning whether if I would like to turn my article into a book. It was then that I started my lifelong exploration of what I later came to call 'green knowledge'. In doing the research for my book, I realised that far from being opposed to science and technology, the people I interviewed – the engineers and politicians and businessmen who were

trying to revive steam cars – were simply trying to make a different kind of science and technology than the scientists, engineers and businessmen who had produced the environmental crisis. They were trying to bring an environmental concern, however vaguely defined it was at the time, directly into the process of making facts and artifacts, that is, knowledge. They were trying to turn knowledge green.

In the following years, as the war in Vietnam intensified and spread to Laos and Cambodia, and the antiwar movement grew more extreme and embittered, it was hard to find a place for my burgeoning environmental interest in the American political scene. I took my search for green knowledge to Scandinavia, where environmentalism had apparently been combined with support for the Vietnamese, and where I found a 'redder' shade of green, infused with a touch of socialism, pragmatic and reformist to be sure, but socialism nonetheless. I joined in the environmental movements that developed in the 1970s in Sweden where I lived and Denmark where I worked and, for another brief moment, I experienced something similar to that feeling I had had back in the spring of 1968.

In both countries, the environmental movements of the 1970s were primarily anti-nuclear movements, and they had a major impact on society, splitting the population but also fashioning new sorts of political and cultural processes. In Sweden, anti-nuclear opposition brought down the social democratic government that had held power since the 1930s and forced a referendum in 1980 in which some 80 per cent of the population voted to phase out nuclear energy within 25 years. It revitalised the tradition of public education through self-organised 'study circles' that had been developed in the early days of social democracy, but which had become institutionalised into the Swedish model of the postwar years and lost much of its radical flavour as a result. I took part in many a study circle, trying to bring my American variety of environmental politics into discussions with biologists and nature-lovers, which I continued to do for many years thereafter in editing a journal of socialist environmentalism, as well as with friends who did not always share my environmental interest.

In Denmark, anti-nuclear opposition was even more successful than in Sweden, stopping the government's plans to build nuclear plants altogether, and nurturing the emergence of the wind energy industry, which now provides some 20 per cent of the country's electricity, the highest percentage in the world. High schools in the countryside, which had grown out of the farmers' movements of the 19th century, provided a base for much of the movement's activity. I was at the Tvind schools in 1978 when the second wing on what was to become the largest wind power plant in the world, was brought out of the workshop by its amateur builders in ceremonial fashion to show what the people could really accomplish if they set their mind to it.

As in 1968, my involvement in the anti-nuclear movement gave me opportunities to learn things together with other people that I could never have learned in a classroom on my own: it was a kind of collective learning. As with the attempted revival of steam cars in the 1960s the anti-nuclear movement provided a meeting place for people from different backgrounds to make knowledge together: engineering students who wanted to show that energy could be produced in an ecological way, biologists who were concerned about the risks of nuclear radiation on their beloved nature, socialists who didn't like the power relations in the nuclear industry, and ordinary citizens who wanted to make their voice heard and take a little power back from the politicians. The human energy that was mobilised in the anti-nuclear movement impressed me, and I have spent much of my subsequent academic career trying to understand where it came from, what it meant, and what happened to the knowledge that was produced in the process: how it came to be culturally appropriated (Hård and Jamison, 2005). As I have tried to understand green knowledge, I have had to transgress disciplinary boundaries, and assume what I have come to think of as a hybrid research identity, combining the engagement of the activist with the intellectual ambition of the academic, and for that matter, the abstractions of the theorist with the details of the empiricist.

CHANGE-ORIENTED RESEARCH

The kind of research I have done is part of a much broader transformation of knowledge – making that has taken place since the 1960s when so many of the assumptions that had traditionally governed scientific research were fundamentally questioned and began to be overhauled. In our time, the boundaries that, for some three hundred years, had separated science and technology, and knowledge – making in general, from the surrounding society have largely been broken down. The relative autonomy of academic institutions and the 'academic freedom' that were once considered essential for the health and vitality of scientific research have been almost entirely eliminated, and even though many of those who work at universities continue to bemoan their passing, there seems to be little value in wishing that they could suddenly be resuscitated.

The integration of science and technology into society was already well underway in many branches of industry, and of course, in the military before the 1960s, but it was accentuated enormously by the technological innovations that emerged in the 1970s: in particular, personal computers and genetic engineering. What have come to be called information technologies and biotechnologies essentially mix what had long been characterised as the

separate spheres of science and engineering, and their ensuing development and societal significance have largely been based on an ever closer collaboration between academics working in universities and people working in commercial business enterprises. Indeed, in many cases, due to the various attractions and not least the wealth that can be accumulated in the commercial marketplace many academics have largely become 'entrepreneurs' in their attitudes, behaviour, and way of life – and many universities have come to resemble business firms in their underlying modes of operation, as well as in the values and norms by which they are administered and organised.

At the same time, scientists have also been interacting ever more intimately with government, or the world of politics. Again, there are many scientists who refuse to recognise the increasing role of politics in academic life, but there can be little denying that the boundaries between science and politics have become substantially blurred. In the United States, this had become obvious already in the 1960s, with many academics serving as key advisers in the war and therefore being subjected to student protest activity (I remember when I came to Harvard people joked about Professor Kissinger spending more time in Washington than he did in Cambridge). In Europe as well, as science and technology, in the course of the 1960s, became ever more central to social and political life, not least because of their environmental 'consequences', and as new government agencies and departments were established to take charge of these new areas, scientists became more and more involved in politics. Thus while in many, if not most branches of industry, the borders between science and business were becoming increasingly transgressed, and in many areas of social science, the traditional boundary between science and policy-making was increasingly crossed, in the humanities, or human sciences, academics such as myself have always been doing something new, namely, carrying out research in closer cooperation with 'activists' or other concerned members of the public who are trying to change things. I call it change-oriented research.

In different areas of social life and in different fields of research, it is referred to by different names – action research, advocacy, participatory planning, public education, technology assessment are all synonyms and reasonable descriptions for the kind of work I do – but what they all have in common is an ambition on the part of the researcher to engage in various processes of social or cultural change. Such research is problem-driven rather than disciplinary-driven, and it involves a range of methods that differ from the traditional methods of the sciences. Much of the research I have done draws on experiences from the progressive movement in the United States in the early part of the 20th century, when 'muck-raking' journalists, social workers, and public health experts, and pragmatic philosophers like John Dewey, carried out projects in urban reform and human ecology,

in occupational medicine and regional development, and not least in public education. Revived in the 1960s, these examples of change-oriented research were complemented by the forms of consciousness-raising that were initiated by Paolo Freire in Brazil and by many of the 'movement intellectuals' who took part in the environmental movements and in the movements of women's liberation that formed such an important part of the politics of the 1970s.

In Denmark and a few other countries in Europe, this kind of research was directly stimulated by the energy debates of the 1970s, which led to the creation of state-supported research programmes in technology assessment, and new methods of interaction between citizens and experts in relation to science and technology. One of the more widely used methods has been the consensus conference developed by the Danish Board of Technology, in which a group of laypeople are brought together in an organised way to question experts on a particular topic of interest and are then given the opportunity to prepare a report where they can propose changes in the established ways of doing things.

The aim of such research is obviously not the same as traditional science. There is little interest in 'proving' an assertion or justifying a truth claim, or in explaining causal relations among different variables. There is also little interest in grand, or abstract theorising, or in what might be called philosophical speculation. Instead, the aim is to intervene creatively and constructively in an ongoing social or political process: to contribute to change. Rather than the traditional notion of enlightenment, by which is usually meant that the role of the scientist is to provide insights for the broader society, derived from a 'disinterested' pursuit of the truth, change-oriented research is about empowerment, by which the researcher applies knowledge gained from experience to processes of social learning, carried out together with those being 'studied'

Already as an undergraduate, I had begun to realise that science and technology, and the roles that they played in society, were in the midst of fundamental change. There had been an enormous expansion of science and technology in the period after the Second World War, both for military purposes, as well as for other 'missions' – such as landing a man on the moon. Science, which had previously been considered 'pure' by many, if not all of its practitioners – that is, free from outside influence in terms of substance and organisation – had become ever more applied to particular social tasks, and ever more subservient to interests and values other than the purely academic. As could be seen in relation to the war in Vietnam, social and human scientists were also subjected to these new conditions; the rise of what John Kenneth Galbraith (1967) termed the 'new industrial state' had brought about major changes in the interaction between the public and private sectors in the development of new technology. Technological

development, derived directly from scientific research, had become a key factor of production and one of the main contributors to economic competitiveness. In the course of the 1960s, these transformations had led to changes in the ways in which scientific knowledge was thought about by philosophers and scientists themselves.

In accordance with the language that was presented in the influential *The Structure of Scientific Revolutions* by Thomas Kuhn (1962) knowledge making had become normalised, or as Jerome Ravetz (1971) called it, 'industrialised'; social, or external interests had come to steer the cognitive frameworks, or paradigms by which scientists organised their research. Rather than choosing for themselves the topics that they would investigate, scientists had become enmeshed in elaborate systems of research and development, or 'R&D' by which scientists at universities were connected to business firms and government departments in various programmes of 'big science'. Universities, in turn, had largely become factories for producing knowledge workers who served to bring the ideas generated at research laboratories as quickly as possible to the commercial marketplace. The process of innovation was coming to be recognised as a central topic for economists and business managers, and the relations between science, technology and society were beginning to be investigated by academic experts, as well as by new cadres of science politicians and policy makers.

By the 1970s, programmes had begun to spring up at universities, and it was at one such place – the Research Policy Program at the University of Lund – where I started to carve out my particular approach to research. The first few years were primarily a continuation of the journalism that I had carried out at college, but gradually, I was introduced to the emerging field of science, technology and society studies, or STS, which served as a meeting place for what had previously been an abstract philosophising about science and empirical investigations of what Bruno Latour (1987) later termed 'science in action'. From the outset, I combined my 'expertise' in STS with an interest in environmental politics, and through the years, I have mixed my two 'subjects' in various ways. What has remained central has been the 'cognitive approach' to reality, a focus on the knowledge making that goes on in society, and, in particular, the making of knowledge within the world of environmental politics.

THE COGNITIVE APPROACH

It was never my intention to become an 'expert' in environmental movements, but for both internal and external reasons (it was both what interested me and what I could get funded) my post-doctoral research career

began with a project in the 1980s on the relations between political strategy and knowledge interests in the environmental movements in Sweden, Denmark, and the Netherlands. We were a group of former activists who brought different kinds of competence into the project: Ron Eyerman, a fellow American émigré, was a social theorist, who had written about ideology and intellectuals, Jacqueline Cramer was a biologist and STSer, who had written about ecologists in the Netherlands, Jeppe Læssøe was a social psychologist, who had studied the cultural dynamics in NOAH, a Danish environmental organisation in which he was active, and I was a doctor in theory of science, which was a field that had broken away from philosophy in the 1960s to connect philosophy to empirical research. The project led to a comparative history of the movements (Jamison et al., 1990), as well as to a new approach to social movements: the cognitive approach, which combined theory of science and social theory in a kind of hybrid combination (Eyerman and Jamison, 1991).

Ron and I had both read *Knowledge and Human Interests*, by Jürgen Habermas, in which he discussed the different human motivations for knowledge-making. Where the technical-natural sciences were interested in instrumental knowledge, and the social sciences were interested in administrative knowledge, the human sciences were interested in reflective or emancipatory knowledge. Habermas was updating in his book the categorization of knowledge into three types that had been a part of the theory of science at least since Aristotle, and for us it provided a framework for deconstructing the knowledge that was made in environmental movements. We rephrased the categories into three dimensions of what we came to call 'cognitive praxis': a cosmological dimension, a technical dimension and an organisational dimension. We then went on to use these categories to analyse the ways in which knowledge had been made in the environmental movements in Sweden, Denmark and the Netherlands.

On the basis of our analysis, we argued that the environmental movements throughout the industrialised world had provided a space, or context in which an ecological cosmology, or world-view, derived from systems thinking and, in particular ecosystems ecology, had been combined with particular technical and practical activities that were organised in newly formed public spaces (here again, we 'operationalised' the abstract Habermasian public sphere to researchable public spaces). As expressed in a number of programmatic works that were published in the early 1970s, there was a kind of 'systemic holism' in the air that provided a shared discursive framework, or cosmological knowledge interest. In books, such as Barry Commoner's *The Closing Circle*, Barbara Ward's and Rene Dubos' *Only One Earth*, Edward Goldsmith's *A Blueprint for Survival*, and, perhaps most influentially, *Limits to Growth*, the report to the Club of Rome, ecological

ideas were translated into a programme for social action. Another kind of literature – E.F. Schumacher's *Small is Beautiful*, Ivan Illich's *Tools for Conviviality*, the *Whole Earth Catalogs*, and journals such as *Mother Earth News* in the US and *Undercurrents* in England – were offering perspectives on what David Dickson (1974) called 'utopian technologies' showing how the ecological ideas could be put into practice in the development of alternative technologies, especially renewable energy technologies and organic agriculture. In the movement organisations, there was a very open anti-elitist structure, which, as in many other social movements, before or since made it possible for anyone who identified with the movement's aims to take part in what we came to call 'cognitive praxis': the integration of the three dimensions into a collective learning process.

For those of us who were active in the environmental movements of the 1970s, it was apparent that the knowledge we were making was based on a new 'paradigm' which was different from what was to be found in the established sciences. The concept of cognitive praxis was an attempt to clarify the nature of that new paradigm – and to recognise that there had been – and continued to be – serious differences of opinion about what that new paradigm consists of, both in terms of theory, method, and forms of organisation. There were those who wanted to change as little as possible in relation to the established ways of carrying out research, merely add an environmental concern into science and technology, much like the steam car enthusiasts I had written about in the 1960s. At the other extreme, there were those who posited the need for an entire new kind of science and technology, seeing in the environmental 'crisis' a fundamental turning-point in human history which required a totally new approach to knowledge and to society. But whether reformist or revolutionary – what Murray Bookchin termed environmentalist or ecologist, and Arne Naess termed shallow or deep ecology – certain features distinguished what I have come to call green knowledge from traditional forms of knowledge-making.

For one thing, environmental knowledge is inherently interdisciplinary. In order to understand environmental problems, it was necessary to combine knowledge from different fields of science and technology, and especially to transgress the boundaries between the natural sciences and the social and human sciences. This was, of course, easier said than done. Then as now, it was difficult for many environmentalists with a natural science education to give up their privileged position, to accept the fact that environmental problems transcended their intellectual terrain, indeed that the very concept of the 'environment' was a kind of borderland, a place in between the natural and the social, the human and the non-human. It was a place where nature was affected by society, but also where humanity was affected by nature. It was a place – or perhaps more accurately, a cognitive

space – where humans interacted with, had relations to, or, to wax philosophically, took part in the co-construction of reality with non-humans. How could all that be investigated and conceptualized?

Obviously, there could not be one method that would suit all purposes. This has meant that green knowledge must be referred to in pluralis. As in many, if not most areas of research today there is no one universally recognised form of green knowledge. The knowledge that is produced in order to understand environmental problems and to deal creatively with their resolution is highly dependent on context, or on the specific contingencies in which the problem emerged. Green knowledge is thus a situated form of knowledge making, or collective learning, in that the particular combination of insights and techniques is contingent on setting, on the particular site in which the learning takes place. This means that the ways in which lessons are learned, the ways in which knowledge is exchanged is different from what is involved in the traditional sciences. In many respects, it is more like the pragmatic ‘learning by doing’ that has long characterised engineering knowledge, with the important difference that the knowledge that is learned is never replicable – because the context, in significant ways, is never the same. The particular mix of culture and nature, of the human and the non-human will never be able to generate the exact same response.

Green knowledge is exchanged by example rather than by replication. But the example cannot be slavishly, dogmatically followed the way an experimental method can be repeated in a laboratory. In the ‘laboratory’ of the real world where environmental problems are to be found and dealt with the example has to be recounted; it is by telling stories about what has been done in a particular place that green knowledge can be disseminated and eventually exchanged. Those stories require a particular kind of story-telling, an ecological, or holistic kind of story-telling, an attempt to grasp the whole.

The exemplar remains *Silent Spring*. It is a book of science, but it is also, and even more importantly, a book of ecological story-telling. The facts that are presented – about the effects on human and non-human health of chemical pesticides – are mixed with presentations of the fact-finders, and the cultural history of the environmental problems is told along with the natural history of the landscapes in which the problems are situated. The example is presented not as a particular ‘case’ that has been studied in all of its myriad details, but for its exemplariness, its capacity to awaken other researchers to investigate other examples and tell other stories about the human war on nature, as Rachel Carson called it.

My own modest attempts to follow in her footsteps can further illustrate some of the features of ecological story-telling. In the steam car book, I outlined the problem of automotive air pollution, sketched the political background, recounted the history of steam automobiles and gave a general

overview of different examples before narrowing in on one detailed 'case': William Lear, who had set up shop in Reno, Nevada, to spend some of his many millions of dollars developing a commercially viable steam car (which he eventually did do, but the auto companies were not interested). The examples were meant to illustrate the more general points, not to 'stand alone' or serve as a microcosm for the whole. As such, the general needs to be presented along with the specific, and it is in the mixing, the combining that the story unfolds.

More recently, in *The Making of Green Knowledge* (Jamison, 2001), I tried to tell a different kind of story, a theoretical story, framed by a cultural theory derived from the writings of Raymond Williams. It was the story of an emerging cultural formation, an ecological culture and I tried to tell it as a kind of ongoing struggle between environmentalists and the surrounding society. The story-line was of a multifaceted process of cultural transformation, by which environmental ideas and practices had been appropriated by the surrounding culture, first by providing new words, things and activities, and gradually by transforming institutional, laws and routines, and, not least, forms of knowledge-making.

The plot was of a series of tensions, or conflicts that, in their resolution, led to the emergence of new conflicts and tensions – and what I called dilemmas and ambiguities. I attempted to recount the 'dialectics of environmentalism'. In the 1970s, the conflict over nuclear energy had led to a differentiation of environmentalism between the practical-minded and the theoretically-minded that was resolved at the end of the 1980s by the articulation of a new discursive framework – sustainable development – that served to spread the environmental consciousness much more broadly through the society. By the end of the 1990s, however, sustainable development had also led to a tension between what I have termed 'green business', on the one hand, and 'critical ecology', on the other, the one articulating discourses of ecological modernisation and natural capitalism, and the other linking sustainable development to other discourses of global justice and sustainable community. As such, the emerging ecological culture has been waging a struggle on two fronts: against the dominant commercial culture which attempts to incorporate what Raymond Williams (1977) termed its 'structure of feeling' into established business, and against residual cultures of traditional ideologies and scientific disciplines, which attempt to capture sustainable development in outmoded discursive frameworks, organisational forms and personal identities. In recent years, I have come to see possibilities for resolving the tension both by redefining sustainability – as science, as community, as 'just sustainability' – but also by producing new examples that combine in new hybrid combinations, something of the seriousness of the business people with the passion of the critics (Jamison, 2006).

THE HYBRID IMAGINATION

It might be helpful by way of conclusion to attempt to characterise the tensions that have developed in the quest for sustainable development – and how they might be resolved – in terms of research identities. In this regard, it seems to me that there is a substantive difference between interdisciplinary and transdisciplinary approaches to green knowledge. Both are attempts to transcend the traditional disciplinary identities that were so important to scientists and engineers in the past, but which have become increasingly difficult to sustain, because of the external pressures that scientists and engineers and all other knowledge makers are increasingly subjected to. Thus, while there is a fairly widespread promulgation of a 'hybrid imagination' and a general recognition of the importance of flexibility and mixing and the combination of skills and knowledge, there are very different forms in which the hybrid imagination is being put into practice.

As ideal types, we can distinguish between interdisciplinarity, which, at least for me, is something that emerged in the 1970s as a goal for many scientists, who were interested in contributing actively to the social challenges of the time, and, not least, to the social movements that emerged at the time, and transdisciplinarity, which started to be used in the 1980s as a term to characterise those working in the ever more commercialized and globalized world of 'high-tech' knowledge making. Where the one signals a primarily internally generated process of knowledge integration, the other signals a largely externally generated process of knowledge combination.

Within interdisciplinarity there is a further distinction between what might be termed as collaboration – in which a real synthesis of different knowledge takes place (as in my books with Ron Eyerman) – and cooperation – in which people with different disciplinary backgrounds work together on a common project (as in the first volume that Ron and I wrote with Jacqueline Cramer and Jeppe Læssøe). Both are internally generated and involve integration of knowledge into something more comprehensive or collectively shared, but whereas the one involves the making of a true hybrid, or joint work, the weaker form, cooperation often results in a collection, a group work, usually an anthology of some kind that is more or less integrated.

Similarly, within transdisciplinarity, it is possible to draw a distinction between a stronger form – which can be characterised as explicit nondisciplinarity, or even antidisciplinarity – by which the research identity is derived from expertise in a particular technique or concept or method, that has little connection to any particular academic field, but which is widely applicable in combination with other specialised competencies – environmental

impact assessment is perhaps a good example of what I mean – and what might be termed subdisciplinarity, by which the researcher largely retains a disciplinary identity but transcends downward, so to speak, specializing within a disciplinary matrix or framework in order to have an expertise that is combinable with other subdisciplinary competencies. The various environmental subdisciplines, such as environmental sociology, environmental chemistry, environmental engineering, can illustrate what I mean. In all four types, disciplinarity has been transgressed, but in very different ways. In cultural terms, interdisciplinarity is a highly personal process, or series of processes of self transformation, while transdisciplinarity involves the seeking of niches in a competitive market, in a process or series of processes of furthering self-interest.

Obviously, in the contemporary world, there is a need for all four types of hybridization, but what is perhaps most important to emphasise is that one type should not, and indeed must not, be favoured at the expense of the others. There needs to be room – and acceptance – of plurality and of the crucial importance of both personal engagement and what might be termed enlightened self-interest. In some contexts, where it is primarily public participation and cultural change that need to be fostered, there must be opportunities for what I have termed interdisciplinary research, and in particular, for research in which academics and laypeople collaborate in efforts that are organised ‘from below’ in relation to local needs and concerns. In other contexts – in relation to global problems such as climate change and biodiversity – there is a need for transdisciplinarity, by which different types of experts with different forms of specialised skills and knowledge, provide new sorts of technological solutions, or ‘fixes’ to particular problems.

The challenge for the future, for science and society alike, is in finding a proper balance between personal engagement and specialised expertise – or, in other words, between sustainable communities and sustainable growth. What is involved are two rather different cultural value systems, or structures of feeling. On the one hand, there is the democratic, or political motivation to provide opportunities for people to take part in dealing with the challenges that confront them, and on the other hand, there is the instrumental, or economic motivation to provide real solutions to real problems. Much will depend on how well we as academics and as citizens manage to combine those two ambitions, or motivations in the years ahead.

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Innovation for Sustainability in a Changing World

The South African-German Dialogue on Science for Sustainability

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SOUTH AFRICA AND GERMANY IN DIALOGUE

The South African-German Dialogue on Science for Sustainability (D4S) between the South African Department of Science and Technology (DST) and the German Federal Ministry of Education and Research (BMBF) was initiated in December 2007 in Pretoria, South Africa.

A hundred South African and German scientists, policy makers and representatives of industries and non-governmental organisations participated in the course of the dialogue. The initiative intends to define common areas between South Africa and Germany in the field of research and development for sustainability, build future networks between the scientists and industries in both countries, initiate new research and development cooperations and contribute to the dissemination of scientific and technological knowledge. Importantly, the dialogue aims to provide a forum for the two parties to share knowledge and have focused discussions on a range of mutual policy and strategy challenges.

Based on a Joint Declaration of Intent signed by Mr Mosibudi Mangena, Minister of Science and Technology, Republic of South Africa and Dr Annette Schavan, Minister of Science and Technology, Federal Republic of Germany on 8 February 2008 two conferences were already held. The first session in Bonn, Germany, was a first stocktaking exercise of the bilateral cooperation lines in Science and Technology, Development and Environment. Five priorities were identified for future cooperation. The second dialogue session in Pretoria, 26 and 27 October 2009 aimed at deepening joint understanding of a selected number of policy and strategy issues of interest to players in the national systems of innovation of both countries, refining the dialogue framework developed during the first dialogue session as a basis for identifying new areas of cooperation and agreeing on the next steps for the dialogue and identifying specific areas for enhanced cooperation between the two countries.

In the dialogue, the participants exchanged experiences and scientific knowledge in organising national systems of innovation to support sustainable development, decoupling economic development and environmental degradation, and the role of international science and technology cooperation towards innovation for sustainability.

Both parties agreed to keep the dialogue on the strategic level especially in the cross cutting fields of environmental economy and policy research and innovation for sustainability research. BMBF and DST will discuss possibilities for funding of new joint R&D projects, e.g. in water and environmental technologies, and to continue the dialogue for another three years (2010–2012) under the Agreement on Cooperation in Science, Research and Technology (1996).

BACKGROUND: THE ROLE OF THE SCIENCE POLICY DIALOGUE

Science and technology play a crucial role in meeting the pressing challenges of sustainable development. Having recognised the considerable potential for collaboration in developing cost-effective and innovative technologies, South Africa and Germany entered into a policy dialogue process that aims to strengthen bilateral science and technology cooperation. The dialogue rests on an assessment that both countries face a challenge in combining economic growth with sustainability and agree that the time is ripe for a partnership based on mutual interests in a sustainable future nationally and globally. The dialogue should lead to joint research and sustainability strategies as well as contribute to the development of strong linkages between research, the private sector, civil society and the government, both within and between the countries. Finally, it should assist both countries in not only strengthening the contribution of National Systems of Innovation to support sustainability but also the emerging Global System of Innovation. Both Germany and South Africa are playing leading roles in an OECD project looking at how to strengthen international cooperation to address global challenges such as environmental sustainability.

The partnership draws from the ongoing collaborative projects in the fields of environmental science and sustainable technologies within the existing political framework for scientific and technological cooperation between the Republic of South Africa and the Federal Republic of Germany (See: Intergovernmental Agreement on Cooperation in Science, Research and Technology, 1996).

The dialogue creates links between bilateral and multilateral cooperation lines. A significant milestone was the signature of a Joint Declaration

of Intent on Cooperation in the Area of Science for Sustainability by the German Federal Minister of Education and Research Dr Annette Schavan and the South African Minister of Science and Technology Mosibudi Mangena in February 2008. The Declaration confirms the countries' support for the G8+5 call for an internationally coordinated research agenda as part of the Heiligendamm Dialogue Process and in accordance with the results of the G8 Strategy Meeting on Africa's Science and Technology Consolidated Plan of Action. In the framework of the UN Earth Summit in Rio de Janeiro (1992) over 170 signatory states committed to translate the vision of sustainable development into practice by adopting Agenda 21, a global action programme designed to achieve sustainable development worldwide. Both countries, the Federal Republic of Germany and the Republic of South Africa, signed Agenda 21 and designed national strategies to promote fundamental political, social, economic and industrial change towards sustainability. Research for sustainability is one of the pillars in these national strategies.

Along the National Strategy for Sustainable Development the South African government adopted the 10-year Innovation Plan in 2007 which identifies five key grand challenges for its National System of Innovation. The need to contribute to sustainable development is reflected in all of the five grand challenges identified in the plan. Three of them play especially prominent roles. Firstly, Energy Security identifies the need for developing and deploying new energy technologies, including renewable energies and energy sources with a lower carbon footprint. Secondly, Human and Social Development identifies the need for new approaches to the challenge of change. Thirdly, the Global Change grand challenge has a major focus on innovation for sustainability.

A comprehensive 10-year Research Plan acknowledges that 'the ways in which human societies engage with their environment to satisfy basic needs, stabilise and grow their economies, and improve their quality of life, affect and are affected by the natural cycles that regulate the land, water, and air'. Changes are occurring so rapidly, however, that greater understanding of the Earth's natural processes, the human influence on these processes, and the interactions between the two, has become a global priority – as has the need to find ways to mitigate these changes where possible, and to adapt to them.

Work is also underway to accelerate the development of other environmental technologies and innovations that would support adaptation and resilience. These include water, agriculture, built environment, coastal protection, environmental monitoring, and environmental rehabilitation. This is located within a broader framework of developing the Environmental Goods and Services sector in South Africa.

Germany has placed sustainability at the core of its economic and social development agenda. Specifically, the German Research for Sustainability is aimed towards:

- developing strategies for social action with the goal of meeting fundamental needs while minimising the risks for the long-term stability of nature and society;
- gearing globalised value chains and production systems to sustainability while simultaneously securing the long-term competitiveness of the German economy;
- shaping regional development with the goal of improving the quality of human life and at the same time stabilising the natural, social and economic bases of this quality of life on a long-term basis;
- managing natural resources with the goal of maintaining their functions on a long-term basis and concurrently preserving and fostering their regeneration capacity as much as possible.

There are important overlaps between these focus areas and three of the four knowledge themes identified in the South African 10-year Global Change Research Plan. These are:

- reducing the human footprint
- adapting the way we live
- innovation for sustainability

LINKING SUSTAINABLE DEVELOPMENT AND INNOVATION POLICY

As we have seen above, sustainable development is one of the guiding principles in both countries' policies and science and technology play a significant role in meeting the pressing challenges of sustainable development. Beyond technology transfer and adaptation to local needs new technologies and services are required. Economic, environmental and social aspects are equally important when looking for sustainable solutions. The lack of attention to sustainability research by top policy-makers and the lack of acceptance of such research by mainstream science need to be addressed.

Germany's experience in sustainability science was shared and the paradigm shift noted from knowledge-oriented to interdisciplinary, solution-oriented research. Germany's first framework programme 'Research for Sustainability' (2004–2009) had four thematic fields of action:

- a. concepts for sustainability in industry and business;

- b. sustainable concepts for regions;
- c. concepts for sustainable use of natural resources;
- d. societal action geared for sustainability.

The second framework programme 'Research for Sustainable Developments,' commencing in 2010, will focus on:

- a. global responsibility – international networking;
- b. earth system and geo technologies;
- c. climate and energy;
- d. sustainable economy and resources; and
- e. societal developments.

As sustainable solutions require a concerted effort and an international coordination of research agendas, BMBF launched a series of dialogues on Science for Sustainability with key emerging economies. The initiative aims to establish the foundations for long-term, strategic partnerships in sustainability research, to increase bilateral cooperation in sustainability-related research, and to develop projects for the dissemination of already existing results.

The South African 'Ten Year Innovation Plan' and the plans of South Africa encourage sustainable development, but in linking innovation and sustainable development three issues have to be taken into consideration: firstly, sustainable development strategies need to acknowledge political realities and is not value-free. Sustainable development pathways may differ between developing and developed countries. However, taking into account the strong influence of international governance on national strategies, strategic dialogues between developing and developed countries provide an important policy learning opportunity that can support the development of international policy environments that can support more fair and just outcomes.

Secondly, in many instances supporting the development of green or environmental technologies experience the same challenges and problems as any other technology. In addition, South Africa wants to ensure that the wave of interest in sustainability leads to long-term economic and social benefits for South Africa. As such, a key focus for South Africa remains the building of its National System of Innovation including the introduction of new institutional arrangements that better support commercialisation and R&D-led industrial development. This includes the establishment of a Technology Innovation Agency (TIA) and the development of specialised institutions called Centres of Competence to take forward specific commercialisation opportunities.

Finally, achieving sustainable development cannot happen through technological solutions only. Although it is easier to galvanise business and government interest on the development of new industries and jobs through technology-led approaches, the nature of the sustainable development requires innovations across a broad range of fronts including a better understanding of human and social dynamics and through a range of policy innovations. As such, these areas of research feature strongly in the 10-year Global Change Research Plan that will be implemented. Coupled to the research work, South Africa will be implementing specific mechanisms that enable the science that is generated to inform policy and decision-making. The South African-German Dialogue on Science for Sustainability is one such mechanism aimed at building the science-policy interface.

THE STATE OF THE SOUTH AFRICAN–GERMAN BILATERAL COOPERATION IN SCIENCE FOR SUSTAINABILITY

South African-German bilateral relations in the field of science and technology embrace various projects in manufacturing, technology, innovation systems, biodiversity, and so forth. They are aimed primarily towards generating sustainable innovative technologies and services, and contributing to human capacity development. Apart from sixteen bilateral cooperation formats, there are bilateral and trilateral cooperation modalities. Trilateral and multilateral cooperation can involve several countries. In this case, cooperation draws on the strength of several countries by pulling together financial and human resources. This is a popular form of enhancing cooperation. Other platforms are workshops and seminars. There is also institutional collaboration, or know-how exchange. If these modalities are to be successful in a meaningful way, partners need to identify the objectives and assess the availability of funds.

Research for sustainability has increased in the context of the existing bilateral S&T agreement. The first German-South African Dialogue on Science for Sustainability in 2008 identified five topics for cooperation: environmental technologies and services, global change, sustainable energy use, sustainable resource management and sustainability innovation system analysis. These topics were incorporated into the 2009 call for proposals and three topics of mutual interest were added: biotechnology, nanotechnology and advanced manufacturing. Thus, the proportion of sustainability research proposals under the bilateral science and technology agreement increased from 25 per cent in 2008 to 51 per cent in 2009. Sustainability topics are also already part of the bilateral lighthouse projects funded on a large scale by research organisations, private

sector, DST and BMBF – ‘Inkaba ye Africa’, ‘Biota’, ‘EnerKey’, ‘Communal Waterhouse’, ‘Integrated Water Management Olifants’, ‘GENUS’ – as well as about 20 per cent of about eighty known independent projects.

The overall context for the future sustainability topics are COP-15, green jobs, and the South African REFIT that will also trigger research and development and applied sciences oriented projects in the context of climate change and renewable energy. Furthermore, a German-South African MOU on (renewable) energy cooperation is currently being elaborated. On the environmental side, there is the international climate change initiative by the German Government with eight projects addressing climate change issues in South Africa. On the political level, the Dialogue on Science for Sustainability (D4S) and the meeting of the joint committee which took place at the beginning of 2010 will focus on sustainability projects and programmes. In the future, there will be projects focusing on: earth system sciences, sustainable land management, regional science services centres on climate change and others. One suggestion is to open up the dialogue to the industrial sector, particularly the participation of SMEs in projects under the S&T agreement in form of a joint research call. Consideration could be given to set up a cluster initiative on solar technologies. Similar to the European Union (EU), there could be a technology platform incorporating German and South African research organisations as well as the public and private sector.

THE WAY FORWARD

The partnership between Germany and South Africa has been mutually beneficial and needs to be continued and made more effective. However, two things need to be addressed. Firstly, as there is a set of challenges that have a historical basis, also regarding conceptions of growth, we need to address how we do development and find solutions in an interdependent and resource-limited world. We need to see what challenges we are facing and what they require us to do. Thus, it is important to get the principles and objectives right. Secondly, both countries have very dynamic systems of innovations and although each party has different objectives, there is a need to strengthen the interaction between the two systems, especially when talking about sustainability. The dialogue should be a real partnership and there should be a full acceptance of ownership. A social approach, project orientation and the integration of industry is crucial for the dialogue that will be continued in the period 2010-2012.

The Ecological Economics Synthesis for Sustainability

Post Scriptum Conclusion

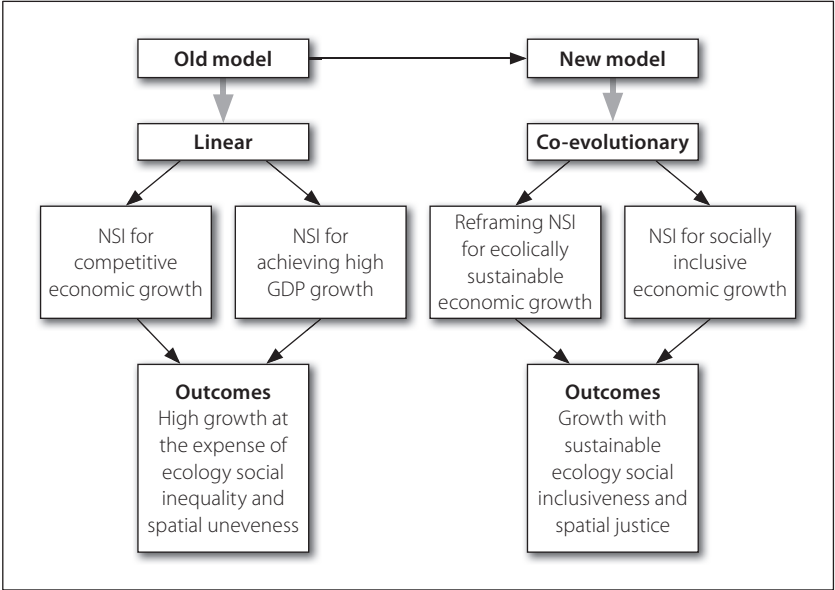
Ecology shares with economics the etymology of 'eco', which means house in the Greek language. But both ecology and economics have evolved by living in different houses, their 'eco' may sound the same, but the eco of ecology, and the eco of economics connote different realities with the same name and with entirely different meanings. This makes it difficult and complex to reconcile a shared sense by bringing out from their separate modes of existence and functioning a common sustainable outcome and logic.

Through out history the ecosystem has been a source for extracting energy, material and food supply and dumping of waste and pollution. This extraction from and dumping to the ecosystem continues, to this day despite the growing environmental awareness in the world. The current economic growth goes through an ecologically extractive and dumping logic and all the sustainable discussions have not changed substantially into bringing about a new reality of an ecologically viable way of economic growth.

The reason why systems of innovation theory is needed is to provide how ecology and economy can be blended into a system in order to bring outcomes that will sustain economic development at the same time with the sustainability of the environment. A new economics that is grounded in ecology and a new ecology that is grounded in economics and both are grounded in social and geographical reality is much needed to create a new paradigm of sustainable economic development. A system approach makes the relationships among the social, the ecological, the geographical and economic to be bonded. These systemic relationships are not external or extrovert, they are internal, interlinked and self-referential. At the moment the ecology, the social, the spatial and the economic exists in non-systemic in the sense they are not casually united or networked to blend the qualities that enhance overall environmental and social well being. For a systemic relation among these variables to take place, there must be internal rules for interconnection among them. The internal bonds make the

interconnections and exchanges to prioritise collaboration and cooperation rather than disruptive competition. A system is not contingent or a field; its main properties are the actors, the activities and the policies internally interact with a logic that can be described and deciphered.

Figure 1 Rethinking innovation system approach for ecologically / socially sustainable development and growth



The old model is linear with outcomes and consequences that do not bring the sustainability of economy, ecology, space and social wellbeing... The new model must be co-evolutionary with the goal of fulfilling economic growth with the sustainability of ecology, space and social wellbeing.

The old model has systems of innovation for competitive economic growth, to achieve high GDP growth by pursuing singularly national and state interest. The higher the GDP and the fiercer the competition, the more the outcome becomes at the expense of ecology, social inequality and spatial unevenness.

The new model reverses this high competitive and exclusively economic growth path with a new system of innovation that bond, interlink, network and embed with each other the economy within ecology and not, as it is taking place now, continue at the expense of ecology, social inclusiveness and regional and spatial disparities.

We have two different models of how the innovation systems approach may be utilised to construct and help design an economic growth strategy that comes at the cost of the ecological, spatial and social relations. This is the current dominant model. Attempts to include ecological concerns in this

logic hardly change the primary and original economic logic. The attempt has been to include ecology within economics into something like economical ecology. The new model needs to change economics with a new logic that embeds the economic with ecology, space and social wellbeing at the same time. This poses a major challenge for innovation systems approach. Research that explores this systematically in Africa is needed.

The different chapters in this volume try to address in part the spectrum of issues of the systems of innovation for economic growth with systems of innovation for ecological economics. The works together open the critical importance of researching the limits of the current dominant economic logic. More substantive research is needed to find ways of the system of innovation that promotes ecological social and spatial economics that can serve as the lens to drive the process of African development and structural transformation that is to be made without transgressing social and environmental constraints and imperatives.

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The innovation system theory has to deal with climate change as it generates the intellectual tools to promote development. A unified innovation system theory that integrates the eradication of threats to nature with the promotion of development is critically important to advance an original pedigree and trajectory of epistemology. Africa must learn and appreciate the costs to itself from the way Europe industrialised. It can neither follow nor imitate the European pattern of industrialisation. It has to include in its own development agenda both the meeting of social needs and choosing a path of development that would not bring ecological harm in the process. The African innovation system has to evolve in a nature protecting – rather than hurting – system; in addition, social needs must be met rather than exacerbating the social inequalities path of development.



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